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Experimental Restoration of Longleaf Pine Community Structure,
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FOREWORD

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Principal Investigator's Signature

30 MARCH, 1998
Date

**Post-Treatment Analysis of Restoration Effects on
Soils, Plants, Arthropods, and Birds in Sandhill
Systems at Eglin Air Force Base, Florida**
Annual Report to Natural Resources Division, Eglin Air Force Base

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PREFACE

This report is intended for the staff of the Natural Resources Division at Eglin Air Force Base. We directed our style and prose to those with technical expertise in forest, wildlife, and fire management. Although we recognize that levels of ecological expertise will vary among our readership, we have attempted to accommodate the majority of those interested in this report. Readers that seek significant or specific results without reading the entire report will be helped by the abstracts included in each chapter, summary tables in selected chapters, the Conclusions and Management Implications chapter, and appendices that provide species lists.

We have written this report in chapters that each focus on specific issues. This format allows the reader to concentrate on a topic of interest without having to read the rest of the report. The new format has resulted in repetition of certain basic information, figures, and references in each chapter. We beg the cover-to-cover reader's indulgence on this point, if any souls are so determined! We have substituted a Conclusions and Management Implications chapter at the end of the report in place of an executive summary. This replacement has permitted us to put the conclusions in a better conceptual context.

The body of the report contains the following sections:

- 1) Introduction – Provides a brief background on longleaf pine ecosystem ecology and restoration, and explains the structure of the report and progress to date;
- 2) Soil Chemistry and Texture – Presents the methods, results, discussion and management implications of the pre-treatment phase;
- 3) Plants – Presents the methods, results, discussion and management implications of the initial post-treatment effects of the large-scale restoration experiment;
- 4) Sand Pine – Presents the methods, results, and discussion of the initial impact of sand pine removal;
- 5) Arthropods – Presents the methods, results, discussion and management implications of the initial post-treatment effects of the large-scale restoration experiment;
- 6) Birds – Presents the methods, results, discussion and management implications of the initial post-treatment effects of the large-scale restoration experiment;
- 7) Conclusions and Management Implications – Synthesizes the management implications previously discussed in each chapter.

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1. INTRODUCTION

Since European settlement, and especially in the last century, the longleaf pine (*Pinus palustris*) landscape has been reduced by as much as 98%, primarily due to clearing for agriculture, conversion to other pine types, and urban development (Noss 1989, Myers 1990). Open-canopied longleaf pine forests once covered an estimated 37.5 million ha (92.5 million acres) in the southeastern U.S. (Frost 1993) and were characterized by some of the highest plant species richness in North America (Hardin and White 1989, Walker 1993, Walker and Peet 1983). These forests are also striking for their variation in vegetation structure and floristic composition (Peet and Allard 1993), which is determined by fire regime (Lewis and Harshbarger 1976, White et al. 1991), soil moisture (Walker and Peet 1983), soil texture (Gilliam et al. 1993), anthropogenic soil alteration (Grelen 1962, Conde et al. 1983), and geographic location (Peet and Allard 1993). A recent study estimates that only 1.3 million ha (3.2 million acres) of longleaf pine stands remain (Landers et al. 1995), which are mostly second-growth, even-aged, fragmented, and isolated. This community has been degraded by past logging, turpentine, grazing, and disruption of natural fire regimes (Means and Grow 1985, Noss 1988, Frost 1993). Remaining old growth stands are primarily small relicts (<25 acres) that have experienced extensive grazing, altered fire regimes, and selective logging (Means 1996). Therefore, restoration of remaining impaired longleaf pine forests has become a high conservation priority.

The measurement of restoration success and selection of feasible metrics that track ecological change in terrestrial systems remains a poorly researched subject (Noss 1990, Hardesty, Gordon et al. 1997), especially compared with methods used in aquatic ecosystem and water quality control research (e.g., Karr 1991, Keddy et al. 1993, Barbour et al. 1996). Myers (1993) has outlined longleaf pine ecosystem restoration (using prescribed fire) based on the following objectives: a) ensure survival of existing longleaf pine canopy; b) reduce accumulated litter; c) reduce numbers of hardwood trees and shrubs; d) prepare the seedbed; e) ensure seedling survival; and f) stimulate understory growth, flowering, and diversity. While several metrics and measures of success were proposed by Myers (1993), time-frames and plausible ranges of endpoint conditions for each metric were not specified. Also, the hardwood and understory species or grouping to measure was unstated, yet this is the information needed by managers to monitor change over time.

In the best of circumstances, restoration success of a degraded site would be measured by comparing the value of several variables (e.g., plant species densities, number of red-cockaded woodpecker [*Picoides borealis*] clusters, and so on) against the range of values for several representative and local sites with high ecological integrity (reference sites) (Gordon et al. 1997). This type of direct comparison to a reference site is generally not possible because old growth longleaf pine forests are rare. Even when old growth longleaf pine is present, determining the representativeness of a reference site can be difficult due to edaphic variation and unknown management histories (Rodgers and Provencher, *in press*). One solution to this problem is found in a study of biotic integrity for Florida streams, where Barbour et al. (1996) identified several reference streams by using multivariate techniques to remove geologic variation from their selection process and to group streams according to their biota. Although the main goal of the study was to identify metrics of ecological condition, their approach could also be used to measure desired endpoints for stream restoration.

In the absence of any local reference site, published botanical accounts from other locations with similar soils and data from experiments may provide the best alternatives for setting restoration goals. Experimental treatments (e.g., White et al. 1991, Rebertus et al. 1993, Streng et al. 1993, Glitzenstein et al. 1995, Provencher et al. 1997) and management activities that imitate the dominant and natural processes (e.g., growing season fire) of a region can reveal the short- and long-term directionality of individual variables (e.g., forb density

increases over time with periodic growing season fire). These treatments that imitate natural processes can then become a benchmark for potentially more effective, but less natural experimental techniques of restoration.

Choosing metrics to track changing ecological conditions depends on human objectives related to these changes. For example, if maximizing longleaf pine regeneration is the only management objective, there is no need to track variables other than those related to this objective, such as pine cone productivity and seedling density. However, most management situations involve a variety of objectives and, in turn, these set the stage for the choice of metrics (DoD-Air Force 1993).

Assuming that management decisions have been made, some metrics (e.g., longleaf pine seedlings) may be inadequate, because they do not respond at the temporal and/or spatial scales of concern (Gordon et al. 1997). By "scale", we refer both to spatial (e.g., home range, average size of a fire) and temporal (e.g., age of first reproduction, frequency of fire or food events) characteristics for the various species and processes in the ecosystem (Gordon et al. 1997). Birds, for example, have a greater home range than many arthropods. Similarly, arthropods occupy larger home ranges than plants and trees. Size of home range is often connected to the sensitivity of a species to local environmental conditions and thus, to habitat perturbations and management activities. For example, we would expect plants to be more sensitive to micro-environmental differences than many arthropods and birds, which can more easily leave an area when unfavorable conditions occur. Birds require more food to feed their offspring and themselves when compared to arthropods. Therefore, birds use a larger foraging area that encompasses a wider variety of environmental conditions. For this reason, birds are not expected to be sensitive to minor and moderate habitat differences (Emlen 1970).

Another important consideration for choosing metrics should be their statistical properties. Many threatened and endangered species are monitored by government agencies (e.g., U.S. Fish and Wildlife Service) and private groups (e.g., The Nature Conservancy) because of legal requirements or specific management objectives. Some of the defining traits of threatened and endangered species are their low numbers and patchy distributions. Thus, we would not expect parametric statistics to be appropriate for these species due to failure to meet the assumptions of parametric statistics. One solution is to sample common species or variable that exhibit similar responses as the threatened and endangered species to natural perturbations or management activities, or that directly influence the species of concern. Herein lies a paradox: a species may be common precisely because it is capable of tolerating a broad range of conditions and is thus unlikely to respond to small perturbation or to restoration activities. Finding sufficiently sensitive metrics among the hundreds of possibilities requires controlled perturbations of ecosystems as performed in experiments. These controlled studies should account for initial conditions that could possibly confound perturbation effects and replicate perturbations (treatments) to minimize the input of confounding variability.

We report on one pre- and two post-restoration studies in degraded sandhills at Eglin Air Force Base (EAFB), Florida, where restoration success was measured and where potential metrics of ecological condition were identified two years after experimental units were treated. We examined pre-treatment relationships of soil texture and chemistry with plant patterns (Chapter 2). We determined the degree of dependence of plant species richness and density on soil texture and whether this effect should be controlled when defining metrics of ecological condition. We experimentally compared the initial effects of three hardwood reduction techniques in fire-suppressed sandhills (growing season burn, ULW[®] form of the herbicide hexazinone, and mid-story mechanical felling/girdling) and a no-treatment control on: a) tree densities and basal areas and on different measures of understory vegetation (Chapter 3); b) arthropod families and species/morphospecies densities (Chapter 5); and c) breeding and wintering bird species detection rates and foraging measures (Chapter 6). We measured the response of plant species densities and richness to sand pine (*Pinus clausa*) removal in

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sandhills where this species had replaced the original longleaf pine in the overstory (Chapter 4).

We conclude the report by reviewing the efficacy of the hardwood reduction treatments and discussing several taxa and variables as potential metrics of ecological condition (Chapter 7). Some of the early data from this work have been incorporated into a separate effort to develop metrics for monitoring ecological condition at EAFB (Hardesty, Gordon et al. 1997). In this report, we continue to refine these metrics and to clarify the processes influencing restoration success in this report. Subsequent monitoring of treatment effects will allow better evaluation of the role of annual variation in assessing ecological condition as well as the dynamics of variables responding more slowly to the experimental perturbations. A timeline of our project is summarized in Fig. 1.1.

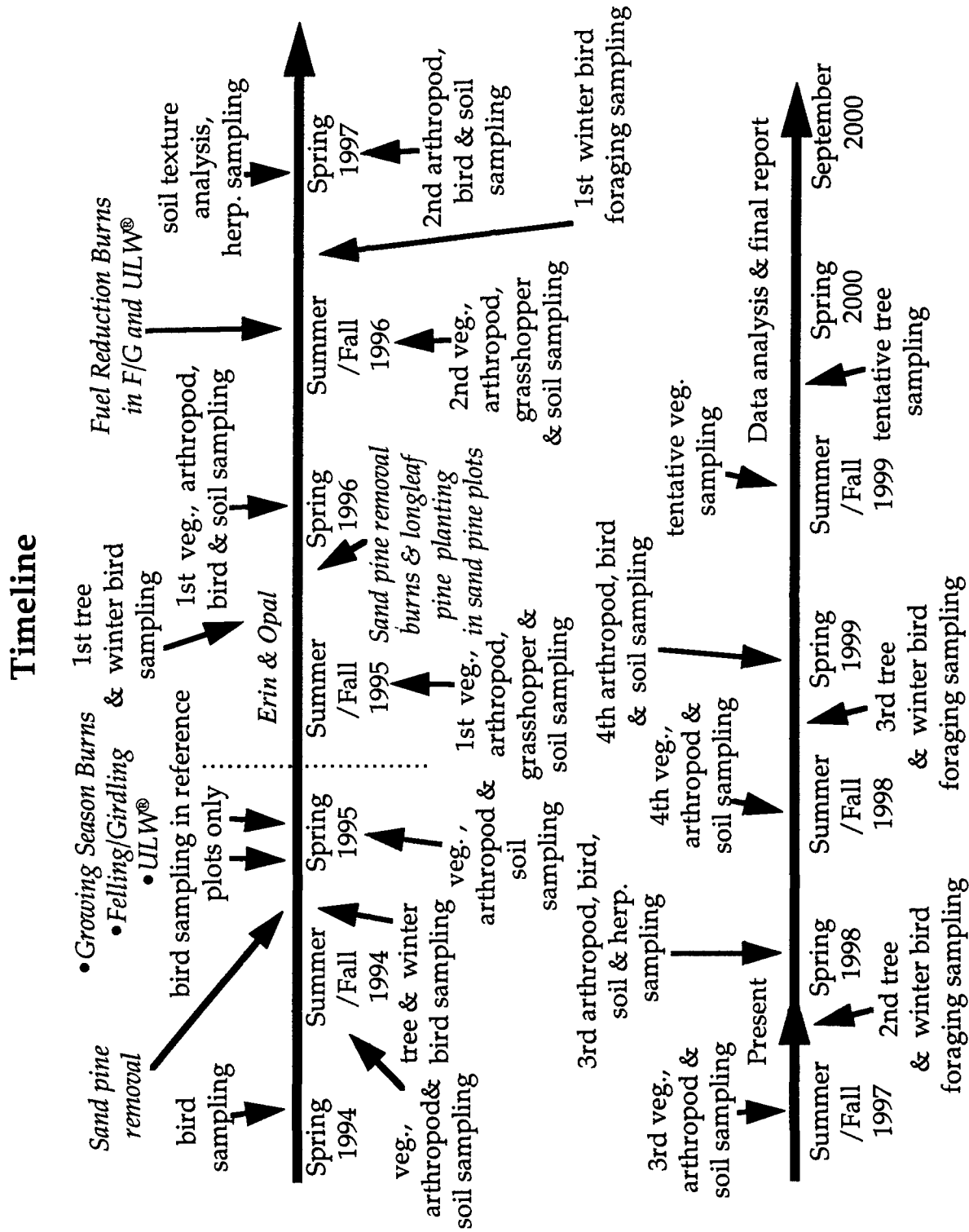


Fig. 1.1. Timeline of the Longleaf Pine Restoration Project. Management activities and hurricanes are printed in italics. The dotted line indicates the end of pre-treatment sampling.

2. PRE-TREATMENT EFFECTS OF SOIL CHEMISTRY AND TEXTURE ON SANDHILL PLOT DISTRIBUTION AND PLANT AND TREE SPECIES METRICS

ABSTRACT

We determined soil chemistry and soil texture from the pre-treatment phase of this study to examine the similarity among 36, 81-ha (200-acre) plots, of which 24 were from fire-suppressed plots, 6 from frequently-burned reference plots, and 6 from sand pine-dominated plots. Using correspondence analysis to group similar plots based on variation among soil chemistry and texture variables, we found that total Kjeldahl N positively segregated plots and that Al, Fe, sand of 0.125 mm, sand of 0.063 mm, and silt negatively influenced the position of plots in multivariate space on the first axis of the ordination. Ca was the only element that separated plots on the second axis of the ordination. Mg, K, P, Cl, pH, percent organic matter, percent clay, percent total sand, and percentages of all other sand size classes had no influence on plot ordination. We found no significant correlation between percent silt in the upper soil horizon and the depth of the argillic layer, but the slope at the location of an auger sample was positively and significantly correlated to percent sand. Soil chemistry and texture variables were correlated to pre-treatment densities of plant species and basal areas of tree species. The number of plant species was positively and significantly explained by percent silt and by the percent of extreme sand size classes, and negatively explained by the 0.25 mm sand size class (dominant sand size). Significant correlations between soil chemistry variables with plant species densities and tree species basal area were generally less than the absolute value of 0.2 and never exceeded the absolute value of 0.31. Correlations between soil texture variables and the same plant and tree variables were greater than for soil chemistry and generally greater than the absolute value of 0.2. The following common species were more abundant on soils with less silt: turkey oak (*Quercus laevis*), bluejack oak (*Q. incana*), sand live oak (*Q. geminata*), catbrier (*Smilax auriculata*), weeping haw (*Crataegus lacrimata*), arrowfeather (*Aristida purpurescens*), wireweed (*Polygonella gracilis*), and bracken fern (*Pteridium aquilinum*). We suggest that the positive correlation between silt and plant species richness should be considered by Eglin Air Force Base's land managers if they include plant species richness as a metric of ecological condition.

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The influence of environmental controls on community composition has been investigated for many terrestrial community types (Rome 1988, McDonald et al. 1996, Motzkin et al. 1996, Ranne et al. 1997). On regional scales, climate and geologic histories often play an important role in determining floristic variation within major biomes (Monk et al. 1990, Peet and Allard 1993). On smaller scales, soil properties, disturbance histories, and their interactions may become primary controlling factors on plant community structure and composition. The interactions between local variation in environmental factors (e.g., soil nutrient levels, soil moisture, fire regime) and spatial heterogeneity of vegetation are important considerations when quantifying potential metrics (e.g., indicator species, species richness) for restoration and management planning.

The longleaf pine (*Pinus palustris*) high pine, or sandhill, ecosystem occurs on a variety of soils across the southeastern United States ranging from fertile sandy clays to infertile coarse sands (Myers 1990) to stony mountain ridges in the Blue Ridge and Valley Province of Alabama and northwestern Georgia. Soil texture, which may relate to nutrient levels and soil water percolation, has been documented to influence the dominant tree species in sandhills across the southeast (Gilliam et al. 1993). (Texture is a useful variable to examine because it integrates nutrient levels and water availability in soils.) Longleaf pine is capable of

dominating across a range of textures, while hardwoods invade fire-suppressed sandhills predominantly on finer texture sands (Wells 1942; Gilliam et al. 1993). In their regional analysis of longleaf pine vegetation, Peet and Allard (1993) reported a strong controlling influence of soil moisture on community composition. This study also suggested that soil texture may exert strong controls on herb diversity and understory development (Peet and Allard 1993). Rome (1988) observed a similar correlation between soil moisture and vegetation variation in pine-wiregrass savannas with species richness being highest at intermediate moisture levels.

Frequent, lightning-generated fire, as well as human-derived fire, has been a common environmental force within the sandhill ecosystem. Various researchers have described effects of fire on sandhill soil chemistry and nutrient cycling, and not all of their reports agree completely. Several examples document that the effect of fire in low nutrient systems is to mobilize nutrients that are either lost through volatilization and leaching, or rapidly taken up and sequestered by the recovering vegetation (Kellman et al. 1987). Christensen (1993) reviewed the effects of fire on soil nutrient levels in longleaf pine systems. As a consequence of fire, nitrogen losses of 2.2 g/m² on xeric longleaf pine sites (Christensen 1977) and 11 g/m² on wetter sites (Wells 1971) have occurred. (The correct terminology would be ustic rather than xeric, but we yielded to the commonly accepted term "xeric".) Soil phosphorus concentrations have also decreased by 47% following lightning season fires (Christensen 1977). Finer textured soils may retain more nutrients than do coarser xeric soils. Christensen (1977) postulated that winter fires may release nutrients which are then available for plant uptake during the growing season, and result in higher productivity post-fire; fires late in the growing season may release nutrients that leach before plants can respond to their greater availability.

Several authors have documented short-term increases in N, Ca, and other minerals, organic matter, and pH in these systems following fire (Boyer and Miller 1994, Anderson and Menges 1997). While some studies report losses of N, Boyer and Miller (1994) concluded that periodic burns in coastal plain pine stands increased macronutrients while not adversely affecting N and organic matter in surface soils. Fire in flatwood communities can cause increases in available phosphorus, which is generally limiting in these southeastern systems (McKee 1982). Fire can also reduce the soil moisture holding capacity of both surface and sub-surface coastal plain soils by burning the organic layer (Boyer and Miller 1994). In surface soils, macropore space also decreased, therefore increasing bulk density. Thus, fire may affect soil physical properties that will affect the vegetation.

Examination of the effects of fire on scrub soil pH and nutrient levels in central Florida showed minor changes (Schmalzer and Hinkle 1991). Calcium levels increased six months post-burn, nitrate levels were higher after 12 mo, and pH was higher at both monitoring periods. Higher pH is likely related to the release of base cations such as Ca in ash. Higher pH can also decrease the availability of Al and Cu, although the pH change induced by the fire examined was not sufficient to explain changes in those elements. Any changes in other nutrients, which probably decreased due to post-fire leaching, had recovered to the pre-fire level within two years of the fire. The delay before increases in N were observed probably results from an initial reduction and then recovery in nitrifying bacteria (Schmalzer and Hinkle 1991).

Nutrient accumulation was increased by the shrub and herbaceous layer under natural *Pinus caribaea* stands during the first year following fire in Belize (Kellman et al. 1987). The authors suggest that the proportionately large quantities of nutrients that can be immobilized in these understory layers, and the speed with which this immobilization can be achieved, indicate an important nutrient conservation role for this ecosystem component in an oligotrophic environment. This role will be particularly important after periodic prescription burning, and after thinning and harvesting of the pine overstory when tree root uptake capacity is reduced or eliminated and large quantities of nutrients are deposited in slash (Kellman et al. 1987).

On Eglin Air Force Base (EAFB) the sandhill ecosystem is found primarily on two soils: Lakeland (Typic Quartzipsamment) (Evans et al. 1996) and Troup (Grosarenic Paleudults) soil series (Boyer and Miller 1994). The Lakeland series is a rapidly permeable eolian sand with little to no soil development. Troup soil is a moderately permeable sandy soil with an argillic (clay) horizon underlying the sand at a depth of about 2 m. Troup series are a highly weathered, mature soil, whereas the Lakeland is an immature soil. The weathered soils are low in mineral nutrients; any nutrients retained are associated with the limited amounts of organic matter present. Both soils are generally acidic, with high leaching and oxidation rates, resulting in low concentrations of nitrogen and other nutrients (Brown et al. 1990). The differences in physical properties of the Lakeland and Troup soils could result in marked differences in plant production and community organization. For instance, higher proportions of silt and clay should increase soil nutrient and water holding capacity which may increase site productivity, recruitment, and species composition (Brady 1974).

In this study we examined pre-treatment soil chemistry and soil texture data. The objectives of this study were threefold. First, we used soil chemistry and texture data to determine similarities among fire-suppressed, frequently-burned reference, and pre-removal sand pine (*Pinus clausa*)-dominated sandhill plots based on multivariate ordination techniques. Second, we attempted to relate soil texture data to soil type (Lakeland and Troup soils), as delineated by Natural Resources Conservation Service soil surveys. Third, we correlated soil chemistry and texture variables to several vegetation variables. We correlated soil texture variables to plant species richness to test the idea that plant species richness increases with percent silt. We also correlated soil chemistry and texture variables to the density of common plant species and the basal area of common tree species. These analyses should reveal the relative contributions of soil chemistry and texture to vegetation patterns.

SITE DESCRIPTION

EAFB occupies the southern portions of Walton, Okaloosa, and Santa Rosa counties in the western Florida Panhandle (Fig. 2.1). EAFB is bordered by the Yellow River and Alaqua Creek to the north and east and by the Gulf of Mexico and Choctawhatchee Bay to the south and east. Sandhill sites selected for this study varied in degree of past fire frequency, soil alteration, and groundcover dominants.

With a historically high fire frequency (approximately 1-10 years), the longleaf pine sandhill community is characterized by a nearly pure overstory of longleaf pine, a sparse midstory of hardwoods (oaks and others), and a diverse groundcover dominated by native perennial graminoids and forbs (Myers 1990). Following extended periods of fire suppression, a dense midstory of hardwood tree species develops, and groundcover of graminoids and forbs significantly decreases (White et al. 1991, Robbins and Myers 1992). Fire suppression also results in increased importance of medium statured shrubs (e.g., blueberries [*Vaccinium* spp.]) and woody vines (e.g., catbrier [*Smilax* spp.]) in the midstory. Both historic and present day forestry and military activities have resulted in significant soil alteration across EAFB. Earth mining, tank activity, roads, clearcuts, selective timber harvesting, stumping, fire breaks, and other activities now create a mosaic of disturbances in both fire-suppressed and frequently-burned longleaf pine stands at EAFB.

The climate is temperate with mild winters and hot, humid summers. Winters tend to be somewhat milder near the coast compared to the inland regions (Chen and Gerber 1990). The mean annual temperature is 18.3° C, with approximately 275 freeze-free days per year. Thunderstorms and lightning strikes are frequent during the summer months. Mean annual precipitation is 158 cm per year (DoD-Air Force 1995). Monthly precipitation levels peak slightly during late spring and early summer months and decrease during the winter months. Snow accumulation is rare. Tropical storms are frequent along the Gulf Coast of Florida and

neighboring states. Between 1871 and 1985, 115 tropical storms and hurricanes made landfall within 110 km of EAFB (NOAA 1994).

The terrain is level to gently rolling with occasional areas of steeply inclined terrain. Elevation ranges from 0-100 m above sea levels and the landscape generally slopes to the southwest toward the Gulf of Mexico. The Citronelle Formation (Pleistocene) is the dominant parent material for the surficial sediments (Overing et al. 1995). This formation consists of sand, clay, and gravel with occasional limonite beds, lenses, and pavements. Between the upper soil horizon and the parent material, the solum is often a one to two meter zone of red, loamy or loamy sand. The relative depth and texture of sola of the Lakeland and Troup series can significantly alter soil moisture availability to groundcover plant species. The depth of this zone is independent of elevation or proximity to the coastline (Clark and Schmidt 1982).

Throughout most EAFB sandhills, the Lakeland soil series is the common upper soil horizon. This series is a thermic, coated Typic Quartzipsamments, characterized as a rapidly permeable and strongly acidic sandy soil with nearly level to steep slopes. The Lakeland soil series may be several to as much as 10 m in depth with little to no soil development in the horizons. Generally, the Lakeland series is composed of medium to fine sand and contains 5-10% silt and clay. Commonly associated with Lakeland soils are Chipley, Dorovan, Foxworth, Lucy, and Troup soil series (Overing et al. 1995). Of these, only the Troup Series is present on plots established for this study (as delineated by the USDA Soil Surveys of Santa Rosa [Weeks et al. 1980], Walton [Overing and Watts 1989], and Okaloosa Counties [Overing et al. 1995]). The Troup series is a loamy, siliceous, thermion Grossarenic Paleudults, characterized as a moderately permeable soil with nearly level to steep slopes (Overing et al. 1995). The Troup series are dissimilar to the Lakeland series by having a higher clay content between 1.25 and 2 m depth, and have relatively higher densities of very fine and very coarse sand particles. The differences in texture accounts for the Troup series to be moderately permeable. These differences suggest a slightly higher nutrient and soil moisture holding capacity in the Troup series. In general, Troup series occurrences are widely dispersed, but small in area at EAFB.

METHODS

Experimental Design

Restoration Blocks. Data presented in this report were gathered during pre-treatment sampling of a five-year ecological restoration experiment initiated in 1994 (Provencher et al. 1996). Here we only describe the aspects of the plot layouts relevant to the focus of this paper. We examined soils in 24, 81-ha (200-acre) experimental plots in fire-suppressed sandhills (coded F in Fig. 2.1). The vegetation in these plots is codominated by oaks and longleaf pine and is recovering from varying degrees of soil alteration. We established six frequently-burned, longleaf pine-dominated 81-ha (200-acre) plots as reference sites (coded "R" in Fig. 2.1) to monitor the convergence of treatment plots to desired ecological conditions (Fig. 2.1). In addition, six 81-ha (200-acre) sand pine removal plots (coded "S" in Fig. 2.1) were established in areas of the southeastern portion of EAFB containing a high density of merchantable sand pine.

The layout of the restoration experiment conformed to a split-plot design (Steel and Torrie 1980), although we do not use the corresponding ANOVA to analyze the data here. The whole-plot portion of the split-plot design was a randomized complete block design with four, unreplicated 81-ha (200-acre) treatment plots (treatments were not applied during the pre-treatment phase relevant to this study) per block and a total of six blocks (Fig. 2.1). The subplot portion of the split-plot design (i.e., within a 81-ha plot) was also a randomized complete block design made of 32, 10 × 40-m subplots distributed in 4, 400-m "transects" (= subblocks) of 2 groups of 4 subplots each (Fig. 2.2).

Transects were placed in the 20-ha (50-acre) corner of the 81-ha (200-acre) plot situated farthest away from the other three plots of each experimental block. This feature was needed to accommodate other variables that are not reported here. For each transect, the two sets of four subplots represent spatial treatments; the first set of plots is separated by a 10-m interval (on plot centers) and the second set is separated by a 50-m interval. This arrangement was incorporated into the design to detect sampling step distance effects (results not discussed here). However, mention of this arrangement is important to explain calculation of means, because the independent statistical unit is the average of the four, spatially-dependent subplots. For all analyses presented here, we used the average calculated from the four subplots (sample size = 6 blocks \times 4 plots \times 4 transects \times 2 sampling distances = 192 averages).

Reference Blocks. Reference plots were initially chosen on a structural basis (e.g., low cover hardwood midstory and high cover herbaceous groundcover), but subsequent surveys revealed distinct differences in groundcover dominants and soil alteration histories. Of the six frequently-burned plots, four are characterized by a groundcover of predominantly bluestem grasses (*Andropogon* spp. and *Schizachyrium* spp.) and have been subjected to varying degrees of soil alteration (Rodgers and Provencher, *in press*). The remaining two plots are partially dominated by wiregrass (*Aristida beyrichiana*) and show relatively few signs of recent soil alteration (Rodgers and Provencher, *in press*). All reference plots had received at least one fire within three years prior to sampling; none had burned so recently that vegetation measurements and soil chemistry were influenced by immediate post-fire effects, such as nutrient pulses and recent fuel combustion.

The six reference plots were divided into three blocks of two plots each. Blocking was necessary due to the proximity of reference sites to three military bombing ranges (historically well-burned sites). The subplots (10 \times 40 m) of the reference plots were situated in the central portion of the 81-ha (200-acre) area to avoid edge effects, and the spacing between the "transects" was greater than in restoration plots (Fig. 2.2). Otherwise, the layout of transects, sampling distances, and nested plots were identical to those described for fire-suppressed plots. Thus, for the six reference plots sample size = 3 blocks \times 2 plots \times 4 transects \times 2 sampling distances = 48 averages.

Sand Pine Removal Plots. Sand pine removal plots had very little understory vegetation, and most of the ground was covered with a thick layer of sand pine needles. Each plot contained 32, 10 \times 40-m subplots arranged along four transects. However, differing from the restoration and reference plots described above, these transects originated from each corner and were oriented toward the center of each plot to form an "X" (Fig. 2.2). This and other design details for these sites were suited to our goal of measuring sand pine encroachment from plot edges. Thus, for the six sand pine removal plots sample size = 6 plots \times 4 transects \times 2 sampling distances = 48 averages.

Soil Chemistry and Texture

Soil Chemistry. In all plots, four 30-cm deep soil cores were collected from the corners of each 10 \times 40-m subplot. For each subplot, the 4 cores were mixed to make a single sample, resulting in 32 samples for each 81-ha (200-acre) plot. Each sample was analyzed for: Al, Ca, Cl, Fe, K, Mg, Na, P, pH, total Kjeldahl N, and percent organic matter (Soil Testing Laboratory, Univ. of Fla.). Soil chemistry variables were averaged across each set of four subplots. We used the Mehlich-1 extraction procedure for Ca, Mg, P, K, Na, Al, and Fe. Walkley-Black dichromate methodology was used for organic matter determination. Total Kjeldahl N was determined using the micro-Kjeldahl method.

Soil Type. USDA soil surveys were used to delineate major soil series for all plots in this study in the following counties: Santa Rosa (Weeks et al. 1980), Walton (Overing and Watts 1989), and Okaloosa Counties (Overing et al. 1995). The USDA designations were confirmed by examining 2-m-deep core samples taken from each plot. The depth of the argillic layer was

recorded (if present within 2 m of the surface) as well as noticeable changes in soil texture (e.g., silt and/or clay content).

Soil Texture Analyses. Soil texture analysis was conducted on subsamples of eight 10 × 40 m subplots from each 81-ha experiment, reference, and sand pine removal plot. For each sub-sampling area, two soil cores (30-cm deep) were extracted from opposite ends of each subplot. The two samples were analyzed and averaged for each 10 × 40 m subplot. Roots, detritus, and organic particulates were manually removed from each sample. To achieve maximum disaggregation of soil particles, the sample was gently crushed with a rolling pin (Folk 1980).

Particle size analysis on each prepared sample was performed by partitioning each sample into its respective silt-clay and sand size fractions, and measuring each fraction separately to obtain total textural class ratios (Miller and Donahue 1990). The silt-clay fraction of each sample was analyzed using the pipette extraction method. (Miller and Donahue 1990). Sand and silt/clay fractions were first separated by wet sieving the sample through a 0.063 mm mesh screen with a 50 M solution of sodium hexametaphosphate, $(\text{Na}_6(\text{PO}_3)_6)$, a dispersing agent. The silt/clay fraction was collected and brought to 1 L with $\text{Na}_6(\text{PO}_3)_6$ in a graduated cylinder. Utilizing Stokes Law, different volumes of the silt-clay solution were extracted at specified time intervals following thorough mixing. Silt and clay extracts were dried then weighed. To determine grain sizes, the sand portion of each sample was wet sieved through a mesh screen column of six sizes classes (4.0 mm, 2.0 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm). Each size class was then dried and weighed as a ratio to total sample weight.

Vegetation Sampling

Density, height and DBH (diameter-at-breast-height) of trees (>1.4 m high) were measured in each subplot on restoration and reference plots. DBH of individual trees was determined using a DBH tape, and height was visually estimated in 0.5-m height classes. However, height of longleaf pine >10 m was estimated from DBH measurements using DBH/height equations from an independent data set for EAFB. A clinometer was used in cases where visual height estimates were difficult. Tree viability (i.e., alive, dead, or resprout) was recorded for each individual. For resprouts, DBH and height of the dead bole were measured when resprouts were <1.4 m high. If resprouts extended above 1.4 m, then DBH and height were measured for the largest diameter and tallest resprouting stem. Height and DBH of all longleaf pine within each 10 × 40-m subplot were measured. Longleaf pine juvenile (<1.4 m high) densities were counted based on one-half of the 10 × 40-m area. Turkey oaks (*Quercus laevis*) were sampled within two 5 × 10-m areas situated at the narrow ends of each 10 × 40-m subplot (Fig. 2.2). All other tree species were sampled in a randomly selected longitudinal half (i.e., 5 × 40-m) of each 10 × 40-m subplot (Fig. 2.2).

Understory vegetation densities were estimated in all restoration and reference plots by counting individual plants or stems in four 0.5 × 2-m sub-subplots situated in the corners of each 10 × 40-m subplot (Fig. 2.2). All plants (<1.4 m high) and rooted >50% within each sub-subplot were counted. For bunch grasses and forbs, clumps separated by >10 cm were considered distinct plants. For all species, the number of flowering stems or clumps was also recorded. A "walk-through" of the 10 × 40-m plot was conducted for a maximum of 10 minutes to record the identity of all plant species present.

Statistical Analyses

Soil chemistry and texture. We used correspondence analysis to perform a multivariate ordination of plots and variables (Hill 1974, Kenkel and Orlóci 1986). The original data set was reduced by further averaging the subplot level data to accommodate the software memory requirements (SYN-TAX 5.02; Podani 1995). We averaged all subplot values to obtain one mean per 81-ha (200-acre) plot. Therefore, the analyzed data set had 36 plots. Variables

considered for analysis were pH, Ca, Mg, K, P, Al, Fe, Na, Cl, percent organic matter, total Kjeldahl N, % clay, % silt, % sand, and the following percent sand size classes: 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm. The two larger size classes (4.0 mm and 2.0 mm) were omitted because most averages were null (4.0 mm) or too low and patchy for multivariate analysis (2.0 mm). All percentages were arcsin-square-root transformed (Sokal and Rohlf 1981).

Soil Types. We also performed parametric correlation on the depth of the argillic horizon and the slope where augering was done with organic matter content, total Kjeldahl N, % clay, % silt, % sand, and the following percent sand size classes: 2.0 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm. We conducted these correlations on two data sets. First, we excluded all subplots (of the full, non-averaged data set) where we found no argillic layer within 2 m of the surface (i.e., we removed Lakeland soil subplots and retained Troup soil subplots). Lakeland samples were removed because our data allowed no variation in the depth of the argillic layer in these soils. Only 12 subplots out of 288 had Troup soil detected. Second, we performed the same correlations with the full data set, mostly to inspect the correlations involving slope while also testing for depth.

Vegetation. The second correlations performed were between soil chemistry variables (see above) and the log-transformed number of plant species from fall 1994, the densities of common groundcover plant species or taxa collected in 1994, and tree species basal areas (winter 1994/1995), as well as between soil texture variables (see above) and the same plant and tree species variables.

RESULTS

Ordination

We graphed separately two correspondence analysis ordinations. One was the ordination of the 81-ha (200-acre) plots using the variation among soil texture and chemistry variables. The second ordination grouped soil texture and chemistry variables using the variation among plots. We only retained the first two axes of the ordination since the third one accounted for <10% of the variation.

The ordination of plots was difficult to interpret. (We obtained the same qualitative results for plots with non-metric multidimensional scaling [Kruskall 1964, Kenkel and Orlóci 1986], which is considered more robust than correspondence analysis). Plots on the left side of axis 1 included all sand pine removal plots (S) and reference plot R_{2w} (Fig. 2.3). Plots R_{2w} and S_4 both had dry creek beds with underground water flow (found while augering) (Fig. 2.3). It was also interesting to observe that plots F_{2b} , F_{5h} , F_{2f} , and F_{1f} contained a creek and/or Troup soil. Plots on the right side of axis 1 showed some consistent grouping. For instance, two adjacent plots of F_4 and most plots from block F_6 were situated on the right side of axis 1. Two reference sites from R_3 and R_1 were also located in the right side of the figure. Axis 2 distinguished only four plots, two of which belonged to block F_3 , but these were not spatially adjacent. Other patterns were not obvious.

The ordination of variables, which matched the layout of the ordination of plots (Hill 1974), revealed simple patterns of dependency between plots and soil variables. The right side of axis 1 was strongly influenced by total Kjeldahl N (Fig. 2.4). The left side of axis 1 (negative relationships) was dependent on the following variables in decreasing order of importance; Al, sand size class 0.125 mm, Fe, silt, and sand size class 0.063 mm. The second axis appeared to be positively and only explained by Ca.

Since percentages of silt, 0.125 mm sand, 0.063 mm sand, Ca, total Kjeldahl N, Al, and Fe more strongly explained the ordination of plots, we graphed these for all restoration and reference blocks and sand pine removal plots. Averages of all soil texture variables were also

presented in Table 2.1. It was obvious from Fig. 2.5 (Table 2.1) that for every soil texture variable examined, some plots were outliers. The median percent of 0.125 mm sand varied from a low of 5% in reference block R_1 to a high of 31% in sand pine removal plot S_6 . Sand pine removal plots S_4 , S_5 , and S_6 contained distinctively more of this size of sand than all other plots. Most other blocks and plots varied between 14 and 22%.

The medians of the finest sand (0.063 mm) varied between 1.5% and 4.1%, but maxima ranged up to greater than 10% (Fig. 2.5). For instance, sand pine removal plot S_4 showed the lowest median and the third highest maximum. Blocks or sand pine removal plots with highest percent of this sand also contained Troup soil (F_2 , F_6 , R_2 , S_4 , S_5 , S_6). However, two blocks with Troup soil (F_5 and S_1) did not always show extreme values.

Median percent silt was distinctively higher in reference block R_2 (8.2%) and sand pine removal plot S_1 (7%) compared to all other blocks or plots (4-5.9%; Fig. 2.5). Of the eight blocks or sand pine removal plots where Troup soil was found, only R_2 and S_1 showed correspondingly higher percent silt. Restoration block F_5 , which also held Troup soil, had one of the lowest median of percent silt, whereas restoration block F_1 , where no Troup soil was detected, showed the third highest median of percent silt.

Al was the dominant soil element associated with reference block R_{2w} and sand pine removal plot S_4 in the ordination (Fig. 2.3). Median Al was higher in S_4 (205 mg/kg) than any other plot (<160 mg/kg), but maximum concentrations of this element was greatest for block R_2 (Fig. 2.7). Median Fe concentrations were greater in all sand pine removal plots (>23.5 mg/kg) compared to other blocks (<23 mg/kg; Fig. 2.7). Fe concentrations in reference block R_3 were also high (23 mg/kg). Restoration block F_4 , situated in the extreme right side of the ordination (Fig. 2.3), showed the lowest median Fe concentrations (19 mg/kg; Fig. 2.7). Fe may explain why sand pine removal plots and reference plot R_{3s} were all situated on the left side of axis 1 (Fig. 2.3). Although medians among restoration and reference blocks and sand pine removal plots were not markedly different for total Kjeldahl N (170 to 260 mg/kg), the range of values exceeding the median was greater in many subplots of F_4 , F_6 , R_1 , R_3 (Fig. 2.6; Table 2.2), which were those retained on the right side of axis 1 of the correspondence analysis (Fig. 2.4). Reference block R_2 , restoration block F_2 , and sand pine removal plot S_5 , had the lowest medians and these sites were situated on the left side of axis 1 (Fig. 2.3). Ca concentrations positively explained axis 2 of the ordination (Fig. 2.4). Some subplots of restoration blocks F_1 and F_3 , and, to a lesser degree, from reference blocks R_1 and R_3 showed maximum concentrations of Ca that exceeded those from all other sites (Fig. 2.6). Otherwise, median Ca concentrations were very stable across plots (10 to 17 mg/kg).

Other soil elements and pH not identified as important by the correspondence analysis were presented in Table 2.2. Average pH varied between 4.38 and 4.81 and showed very small standard errors. Average Mg and P were among the elements in lowest concentrations with Mg varying between 2.88 mg/kg and 3.81 mg/kg and P ranging between 1.29 and 1.80 mg/kg. Percent organic matter was lower than 1.18. Average Na concentrations varied appreciably among sites. Reference block R_2 contained concentrations of 9.44, whereas sand pine removal plot S_5 showed half that with 4.47 mg/kg.

Soil Types

For the 12 subplots where the argillic layer was found within 2.0 m of the surface (i.e., Troup soil), we did not find any significant correlation between silt and depth ($P < .05$; Table 2.3a). The only other significant correlation in this data set was between the slope at the point of sampling and the percent total sand (0.6). When considering all 288 observations (Troup and Lakeland soils), we found this correlation remained significant, albeit much weaker (Table 2.3b). Slope was also significantly correlated to five other soil texture variables, and no correlation exceeded 0.29 in absolute value. Positive correlations were with the percent 0.25

and 0.125 mm sands, whereas negative ones were with the percent 0.5 mm sand class, silt, and clay.

Vegetation

Plant Species Richness. The number of plant species was significantly correlated to all soil texture variables, except percent sand of the 0.125 mm class (Table 2.4). The highest correlation was positive and with percent silt (0.39). The large scatter around this relationship with percent silt is clearly seen in Fig. 2.8; most sample points were outside the 95% confidence intervals. Percent sand showed the opposite correlation with the number of plant species (Table 2.4). This result was expected since sand and silt covary negatively. Although percent sand was negatively correlated to plant species richness, only percent sand of the 0.25 mm class conformed to the negative trend ($r = -0.25$; Table 2.4). This sand class represented the majority of total sand (Table 2.1). After percent silt and total sand, percent sand of the 2.0 mm class showed the strongest and positive correlation ($r = 0.34$). Percent sand of the 0.5 mm and 0.063 mm classes were also positively correlated to plant species richness.

Plant and Tree Species Patterns. Of the 308 correlations between soil chemistry variables and plant species densities and tree basal area, none were greater than 0.34 in absolute value (Table 2.5a). Moreover, only eight were greater than or equal to 0.29 in absolute value. Among these, Na and Al accounted for three and two of the correlations, respectively, which were all positive. Ca and Fe, which were detected for their effect on the ordination of plots, showed very few significant correlation with any plant or tree species. The greatest number of significant correlations were associated with Na, Al, and total Kjeldahl N. Na and Al correlated positively with the basal area of longleaf pine. Gopher apple (*Licania michauxii*), probably the most common sandhill species, was not correlated to any other variable. Silver croton (*Croton argyranthemus*), seedlings of sand live oak (*Quercus geminata*), and persimmon (*Diospyros virginiana*) correlated to only one soil chemistry variable. The strongest correlation was negative and occurred between total Kjeldahl N and dwarf huckleberry (*Gaylussacia dumosa*), another very common sandhill species.

The majority of correlations between soil texture variables and plant species densities and tree basal area were significant and higher than those for soil chemistry variables (Table 2.5b). The largest correlation was 0.52 ($r = 0.54$ for wiregrass and $r = -0.48$ for grass-leaf golden aster [*Pityopsis graminifolia*] may not be valid since these species were absent from most plots but abundant when present). Twenty percent of these correlations were greater than 0.29 in absolute value (while excluding % sand which was highly correlated to % silt). It was interesting to note that the basal areas of the most dominant tree species of EAFB, longleaf pine and turkey oak, showed correlations of opposite signs to the same soil texture variables. Percent silt was positively correlated to longleaf pine ($r = 0.41$) and negatively to turkey oak ($r = -0.36$). The percent of the dominant sand class (0.25 mm) was positively correlated to turkey oak ($r = 0.38$) and negatively to longleaf pine ($r = -0.41$). Longleaf pine juveniles were only correlated to the 0.5, 0.25, and 0.125 mm sand classes and the sign (positive or negative) of these relationships were the same as those reported for basal area.

Only two species other than turkey oak correlated negatively to percent silt (thus, positively to total sand and to sand of the 0.25 mm class): Arrowfeather (*Aristida purpurescens*) and weeping haw (*Crataegus lacrimata*) (Table 2.5b). Among the species that were not significantly correlated to % silt, but that were significantly and negatively related to the percent of 0.5 mm sand (negatively correlated to silt) or positively correlated to % sand, were wireweed (*Polygonella gracilis*), bracken fern (*Pteridium aquilinum*), catbrier (*Smilax auriculata*), bluejack oak (*Quercus incana*), and sand live oak.

DISCUSSION

An important result of this study was that soil chemistry greatly influenced the ordination of plots (Figs. 2.3 and 2.4), but soil chemistry at best weakly explained patterns of plant species densities and tree basal areas (Table 2.5a). Gibson (1992) also observed poor soil nutrient-vegetation correlations in southern mixed hardwood and longleaf pine stands in northwest Florida. Correlation of soil elements and percent organic matter with plant densities or tree basal areas never exceeded 0.34. The majority of significant correlations were also smaller than the absolute value of 0.21 (Table 2.5a).

We reported total N and P concentrations that were somewhat smaller than those found by Lee et al. (1983) for two longleaf-slash pine flatwoods from Gainesville, Florida. Mineral soil in these flatwoods had a combined percent of silt and clay of 7%, which was close to that reported here. They found total N and P concentrations to average 275 and 26 PPM (= mg/kg), whereas we recorded maximum total N and P concentrations of 264 PPM and 1.8 PPM (Table 2.2). The obvious difference between EAFB sandhill soils and Gainesville flatwood soils is the greater amount of decomposing organic matter in the latter forests. Although Lee et al. (1983) studied the chemical composition of the organic component of two soils that differed in drainage, they noted that Al, Fe, and organic matter content were the only chemicals distinguishing the two flatwood soils. Lee et al. (1983) attributed the higher concentrations of Al and Fe to complexing with organic compounds in deeper soil horizons because these elements are usually low in quartzose sands (Burger 1979 cited in Lee et al. [1983]), such as Lakeland sands. We suggest that Fe and Al were important in the ordinations presented here (Figs. 2.3 and 2.4), because Fe may have complexed with decomposing sand pine needle litter. Similarly, Al may have bonded with the decomposing vegetation from sites with greater organic matter (S_1 , S_4 , R_3). Higher Al concentrations in the wetter reference plot R_{2w} and sand pine removal plot S_4 may be best explained by the higher cation ion exchange capacities of these siltier soils.

Hough (1982) found that concentrations of total N, P, Ca, and Mg increased with fire frequency. Reference plots in this study have regularly burned in the past decade, but results do not support the claim that these elements should be in higher concentrations there (R_1 , R_2 , R_3) than in fire-suppressed plots. Actually, some of the lowest concentrations of N and P were found in reference plot R_2 and some of the highest ones were in fire-suppressed plots of block F_3 (Table 2.2). We prefer the following alternative explanation. In central Arizona forests, Klemmedson (1987, 1991) showed that available soil nitrogen increased as the ratio of Gambel oak (*Q. gambelii*) basal area to ponderosa pine (*Pinus ponderosa*) basal area increased. Klemmedson (1991) suggested that microbial activity depends on the ratio of pine and oak leaves in the leaf litter, not absolute amounts. Leaf litter produced by gambel oak contains higher levels of nitrogen relative to that produced by ponderosa pine. Hence, as the ratio of oak leaves to pine needles increased, nitrogen mineralization was increased. Klemmedson (1991) also showed that forest soils with higher gambel oak to ponderosa pine litter ratios significantly increased the growth of barley (*Hordeum vulgare*) and ponderosa pine seedlings. This relationship is consistent with findings at the Jones Ecological Research Center in southern Georgia (Kirkman et al. 1996, Hendricks et al. 1996, Boring et al. 1996, Wilson et al. 1996), which demonstrated that a greater proportion of turkey oak leaves compared to pine needles in the litter promoted greater mineralization rates of nitrogen. Also, generally lower nitrogen levels in burned compared to fire-suppressed plots support Christensen's (1993) argument that, in the presence of regular growing season burns, nutrient levels will tend to slightly decline then stabilize. Biomass increases due to fire suppression may result in significant accumulation of nutrients, which may be quickly lost from the system during high intensity fires.

However, nitrogen levels did not differ between fire-suppressed and frequently-burned plots in a predictable manner. Nitrogen levels were lowest in R_2 and F_2 suggesting that fire frequency and, thus, litter C:N ratios may not entirely explain observed differences. A commonality between these two plots was higher soil moisture and stem densities, relative to other plots. As soil moisture availability increases in sandhill communities, there may be a shift in resource limitation to nitrogen. The resulting increase in nitrogen competition may result in increased sequestration to perennial plants tissues, as well as microbial biomass, leading to a net decline in available soil nitrogen (Chapin 1980, Tilman and Wedin 1991).

Correlation between soil texture and plant densities and tree basal areas were generally larger than those for soil chemistry (Table 2.5b). Soil texture (silt and certain sand size classes) also explained, albeit weakly to moderately, spatial patterns of plant species richness. Gilliam et al. (1993) showed that percent clay and sand strongly explained the distribution of longleaf pine and oaks, especially turkey oak, in North Carolina's sandhills. Turkey oak importance value or basal area was positively associated with low percent clay (high percent sand), whereas higher clay content increased longleaf pine values. We observed the same pattern for these trees, except with percent silt and sand (Table 2.5b). Percent clay reported by Gilliam et al. (1993) were slightly higher and more variable than those reported here (Table 2.1).

In addition to turkey oak, we identified arrowfeather, weeping haw, wireweed, bracken fern, catbrier, bluejack oak, and sand live oak to be more strongly associated with soils containing less silt (Table 2.5b). Grelen (1961) attempted a classification of sandhill species from the Florida Panhandle based on the correlation between the depth of the argillic layer and the occurrence frequencies of species. As we have shown, the depth of the argillic layer did not significantly correlate with percent silt in the upper soil horizon where root density is highest (actually, the shallower the argillic layer, the less silt found) or sand (Table 2.3a). For example, he considered turkey oak, blue jack oak, wireweed, and bracken fern ubiquitous species that did not respond to the depth of the argillic layer. We found that these species were more abundant in soils with less silt, and, presumably, less soil moisture. However, Grelen's designations of catbrier and sand live oak as species associated with dry habitats are consistent with our findings.

An interesting result of this study was that percent silt from the upper horizon sand layers showed little to no relationship to a soil's designation as Lakeland or Troup (Weeks et al. 1980, Overing and Watts 1989, and Overing et al. 1995). We observed that surficial samples of Troup soil contained a broader spectrum of sand size classes, but not necessarily more silt. This broader spectrum is normal in older soils (Troup series are a highly weathered, mature soil, whereas the Lakeland is an immature soil) that have experienced reworking and alluvial deposits over geologic time. Many soil samples for which we did not find an argillic layer within 2 m of the surface (i.e., Lakeland soil) had among the highest percent silt (e.g., reference plot R_2). Why greater percentage of silt was not necessarily found in sand that overlays an argillic layer, may be explained by the eluviation (translocation of soil material by the action of water) of silt from the A horizon (0-13 cm) into the AE horizon (13-36 cm) regardless of the depth of the Bt horizon (Miller and Donahue 1990, Overing et al. 1995). In other words, percent silt and clay should be lower in the eluviated upper portion of the soil. Troup and Lakeland soils mainly differ in that the latter has a smaller percentage of clay in the deeper sandy portion but not in the upper eluviated portion, and has a slightly higher silt content in upper horizons (Overing et al. 1995). Percent silt and clay should decrease with depth in Lakeland sand (Overing et al. 1995). These eluviation processes would explain the non-significant, but positive correlation between percent silt and the depth of the argillic layer. However, since the classification of Lakeland and Troup soils for Walton, Okaloosa, and Santa Rosa counties are based on one datum, we have no way to compare the range of percent silt we obtained to those published by the USDA. Obviously, the silt content of Troup soils that we sampled was low, however we cannot determine if it was out of range.

ISSUES OF MANAGEMENT CONCERN

The positive and significant relationship between percent silt and the number of plant species (Fig. 2.8) applies directly to the monitoring of metrics of ecological integrity to be used at EAFB. Assuming plant species richness is used as one of the many metrics of ecological condition (Hardesty, Gordon, et al. 1997), this positive correlation shows that it would not be sufficient to simply report plant species richness from different areas and conclude that those with higher species richness have greater integrity. This reasoning also applies to the densities of plants that significantly vary with silt content. If sampled areas with greater plant species richness also contain more silt and clay, then claims to greater integrity should only be made after the effects of soil texture have been statistically removed from plant species richness.

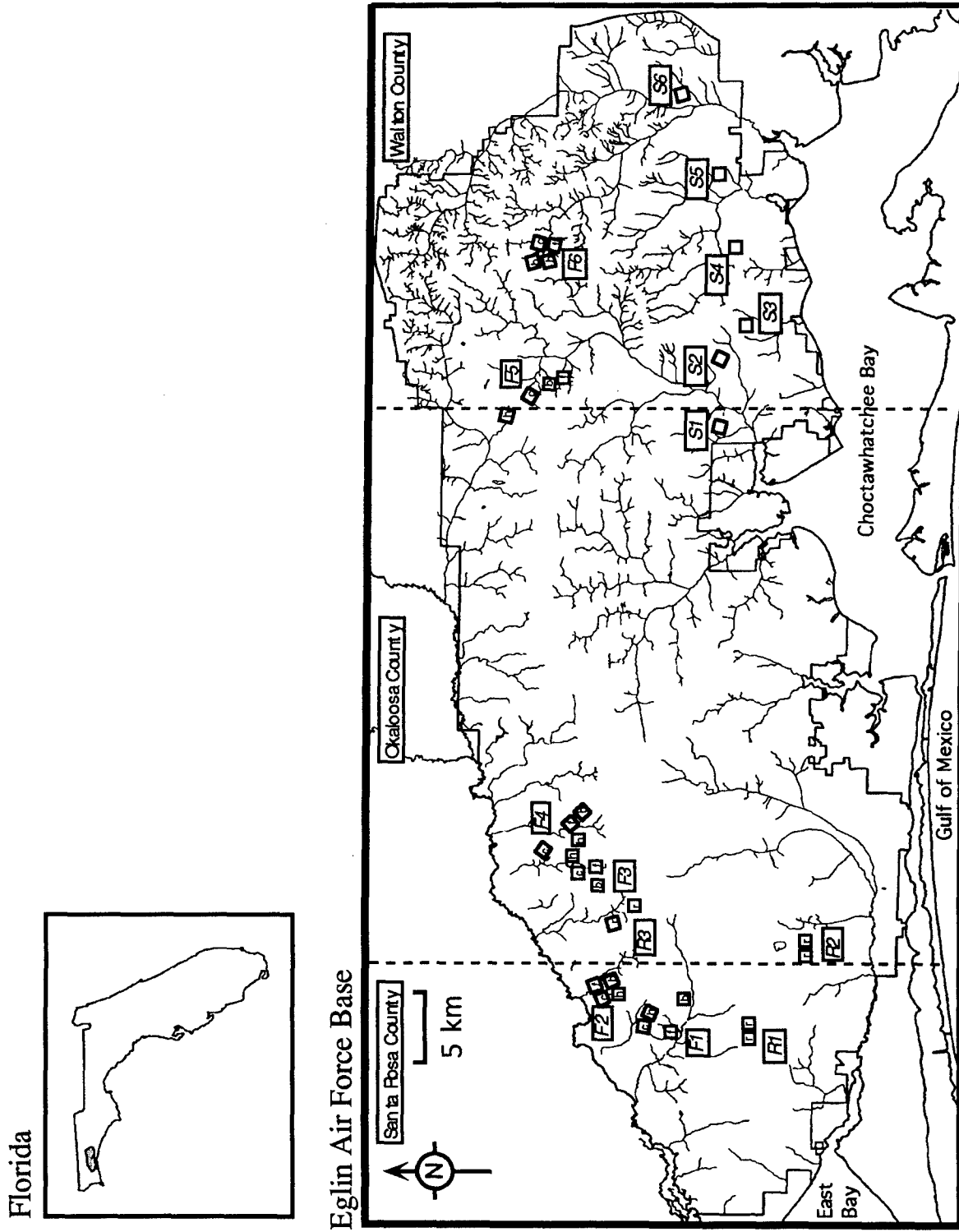


Fig. 2.1. Location of restoration (F), reference (R), and sand pine removal (S) plots on Eglin Air Force Base, Florida. Small squares represent 81-ha (200-acre) plots. Legend: b = burn; c = control; f = felling/girdling; h = herbicide; r = reference.

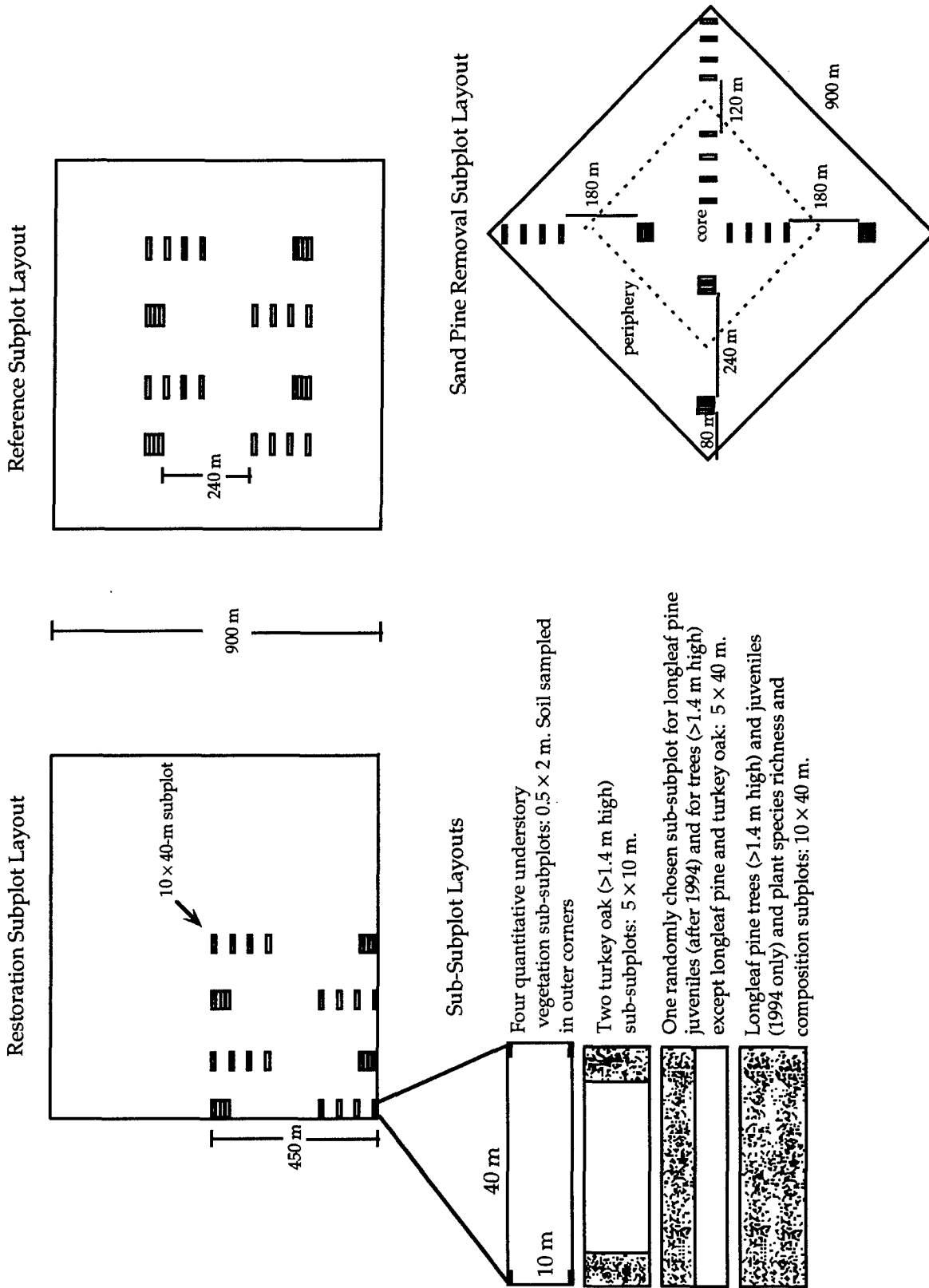


Fig. 2.2. Restoration, reference, and sand pine removal subplot layout. Each plot is composed of 32, 10 × 40-m subplots arranged in 4 transects. Sampling step is 10 and 50 m.

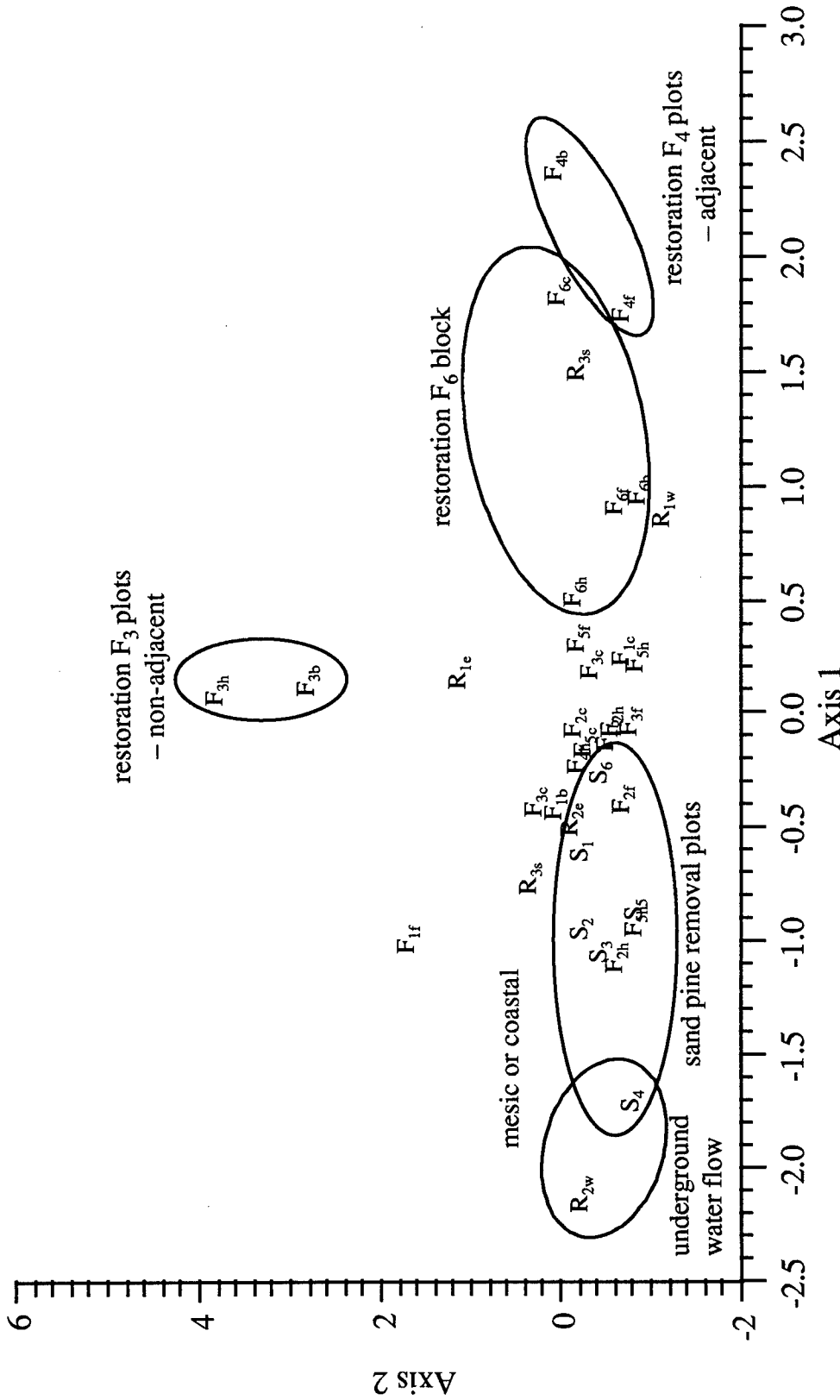


Fig. 2.3. Correspondence analysis ordination of pre-treatment restoration, reference, and sand pine removal 81-ha (200-acre) plots based on soil chemistry and texture variables. Soil chemistry variables were Al, Ca, Fe, K, Mg, Na, P, pH, and total Kjeldahl nitrogen (TKN), percent organic matter (OM). Soil texture variables were % clay, % silt, % sand, and the percent of the following sand size classes (mm): 2.0, 0.5, 0.25, 0.125, and 0.063. Legend: Upper case letters are F = fire-suppressed, R = reference, and S = sand pine plots; lower case letters represent treatments: b = burn, c = control, f = felling/girdling, and u = ULW[®]; plot codes are numbers or e = east, n = north, s = south, and w = west.

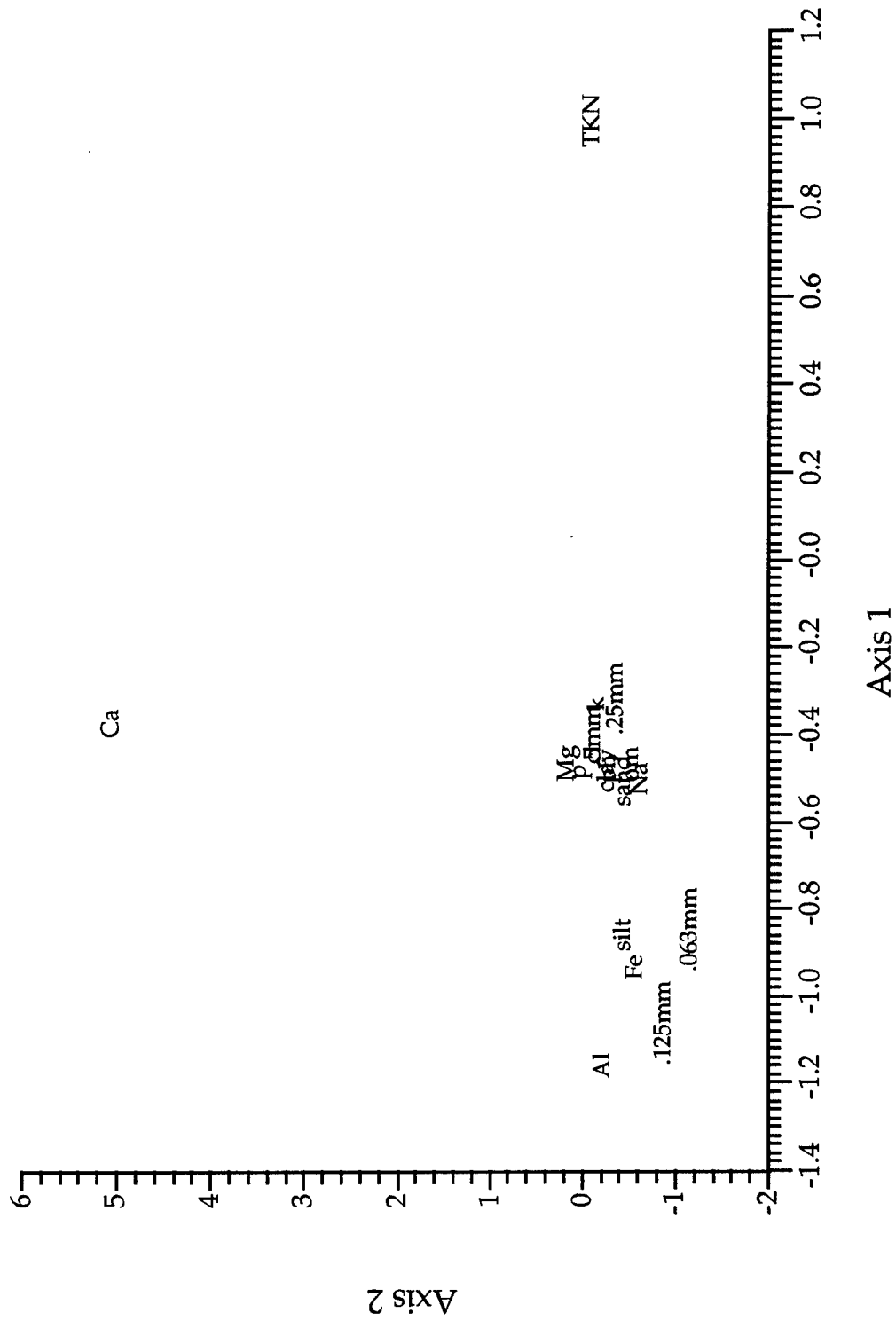


Fig. 2.4. Correspondence analysis ordination of soil chemistry and texture variables based on pre-treatment restoration, reference, and sand pine removal 81-ha (200-acre) plots. Plots and soil chemistry and texture variables presented in Fig. 2.3.

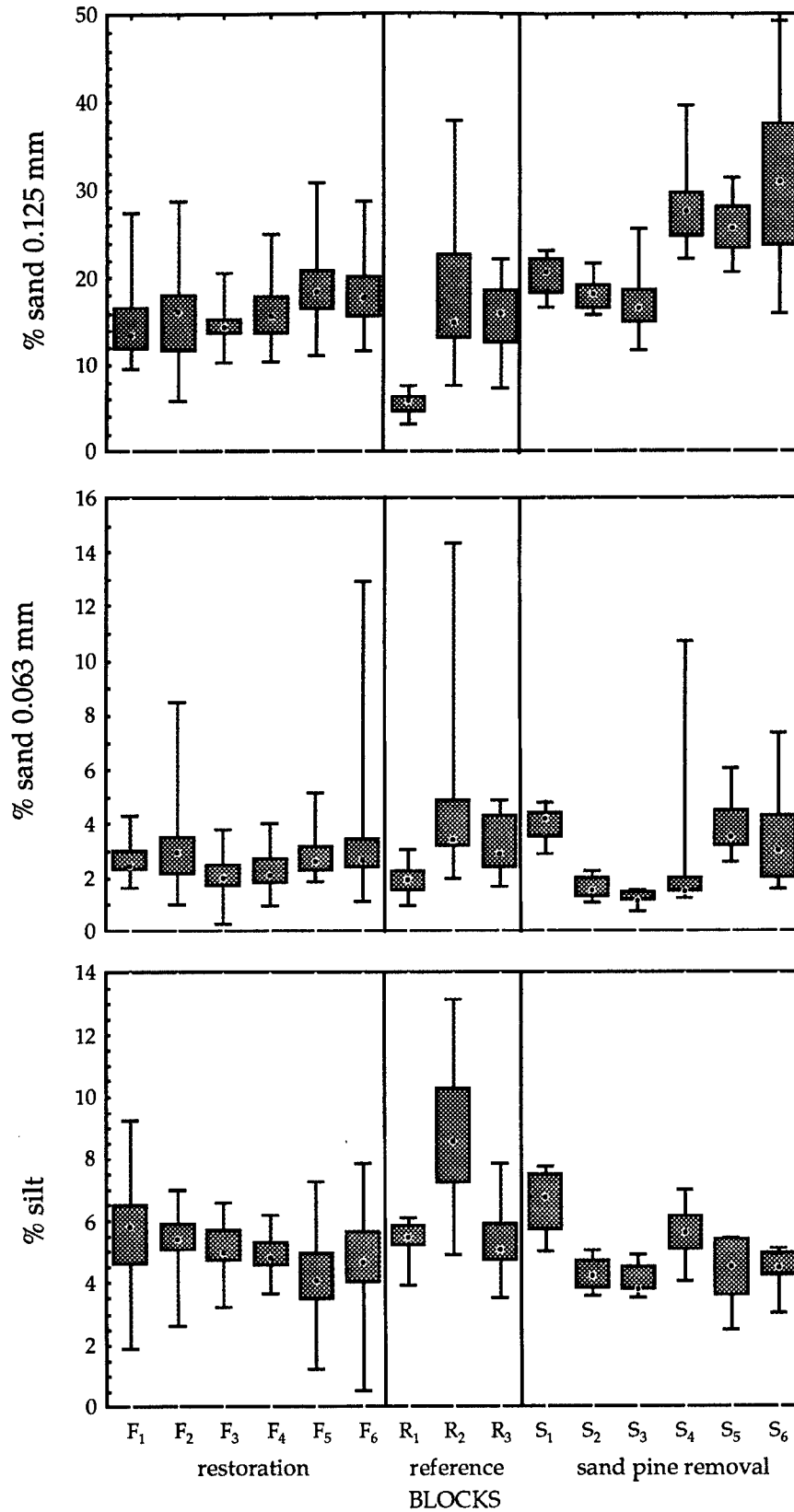


Fig. 2.5. Percentages of silt and sand of 0.125 mm and 0.063 mm from pre-treatment restoration, reference, and sand pine removal 81-ha (200-acre) plots at EAFB, Florida. The center of the box is the median, the edges of the box are the 25% and 75% quartiles, and the error bars are the maximum and minimum. Plot legend as in Fig. 2.3.

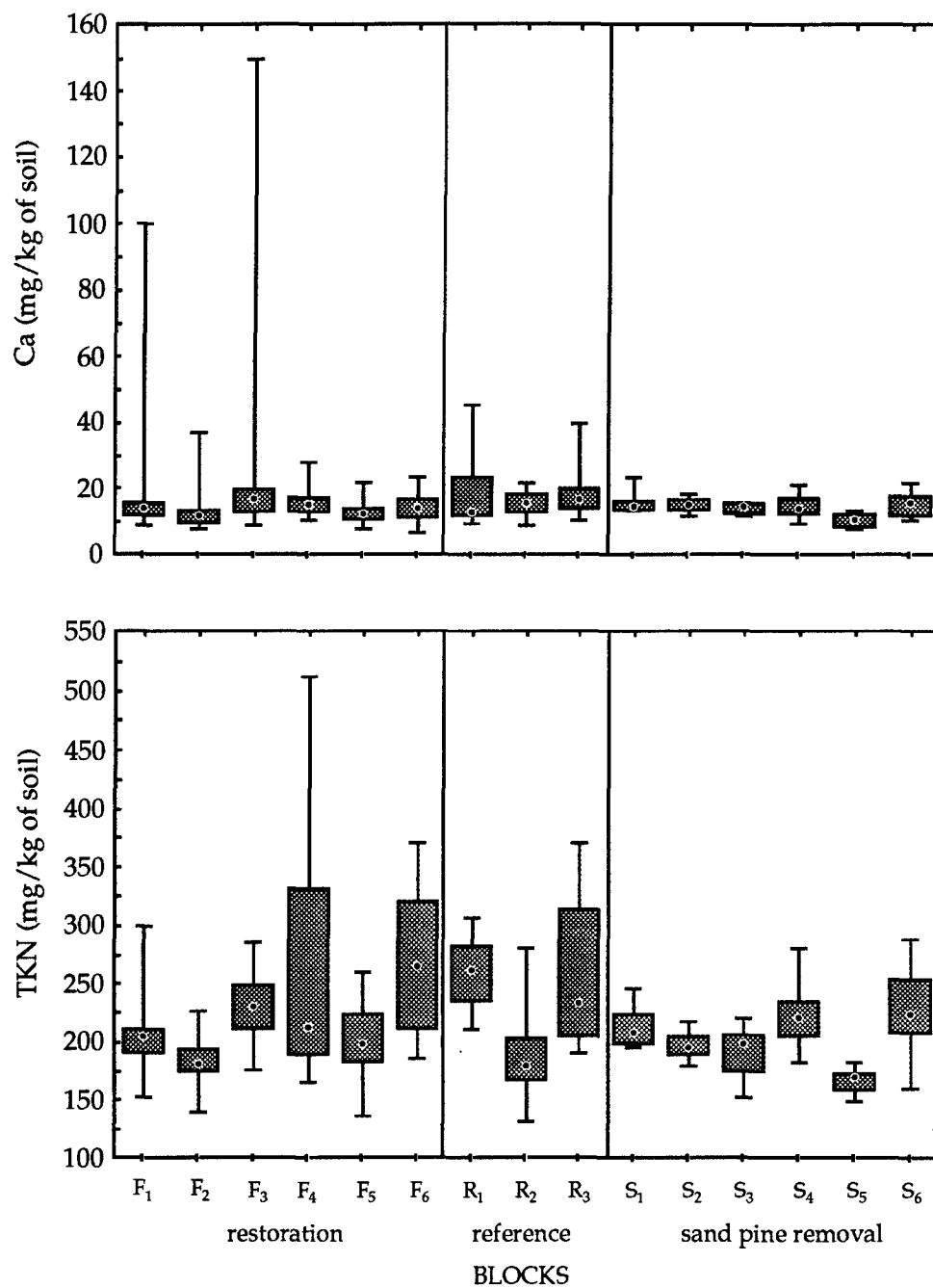


Fig. 2.6. Ca and total Kjeldahl N (TKN) concentrations (mg/kg) from pre-treatment restoration, reference, and sand pine removal 81-ha (200-acre) plots at EAFB, Florida. The center of the box is the median, the edges of the box are the 25% and 75% quartiles, and the error bars are the maximum and minimum. Plot legend as in Fig. 2.3.

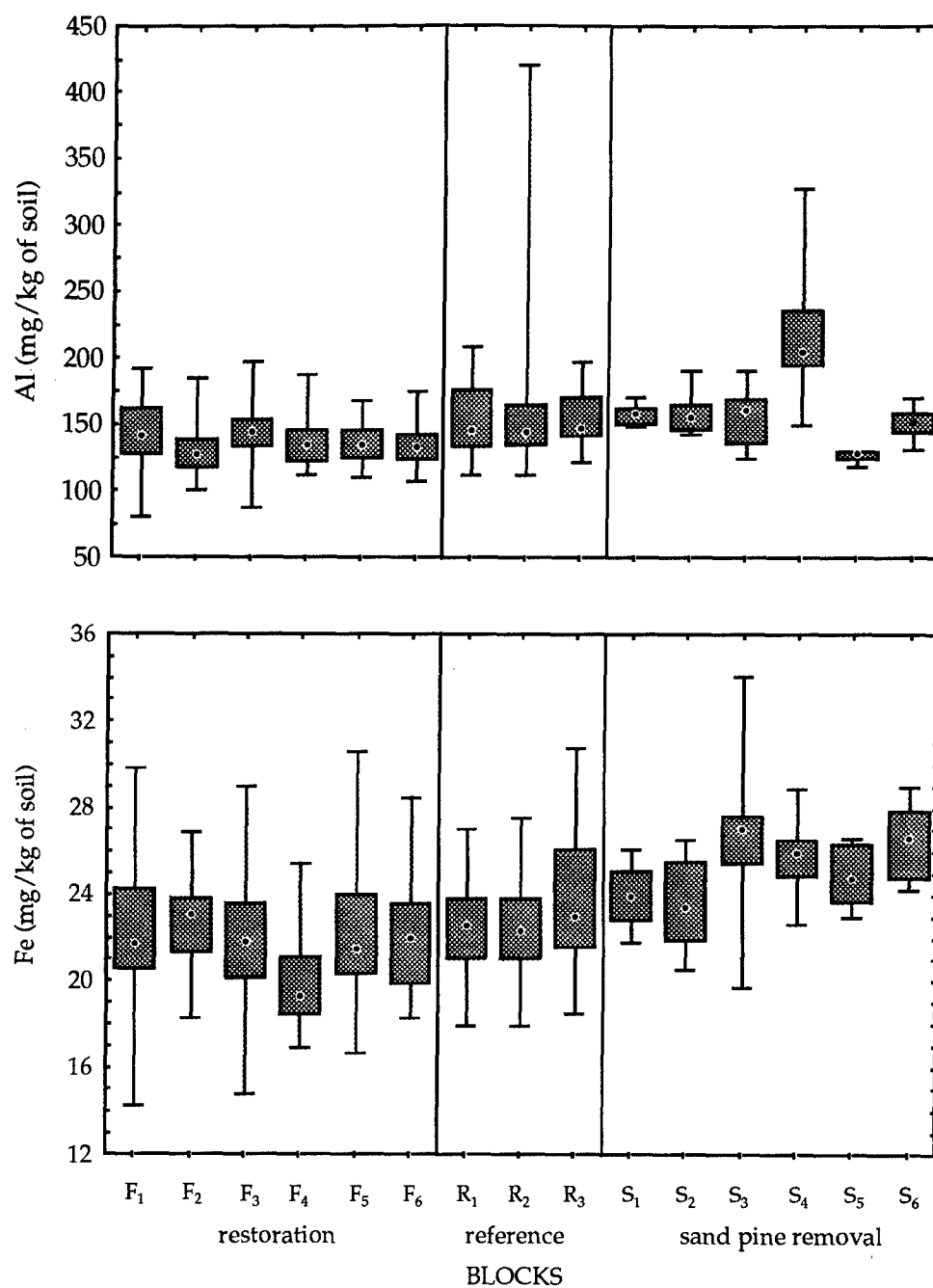


Fig. 2.7. Al and Fe concentrations (mg/kg) from pre-treatment restoration, reference, and sand pine removal 81-ha (200-acre) plots at EAFB, Florida. The center of the box is the median, the edges of the box are the 25% and 75% quartiles, and the error bars are the maximum and minimum. Plot legend as in Fig. 2.3.

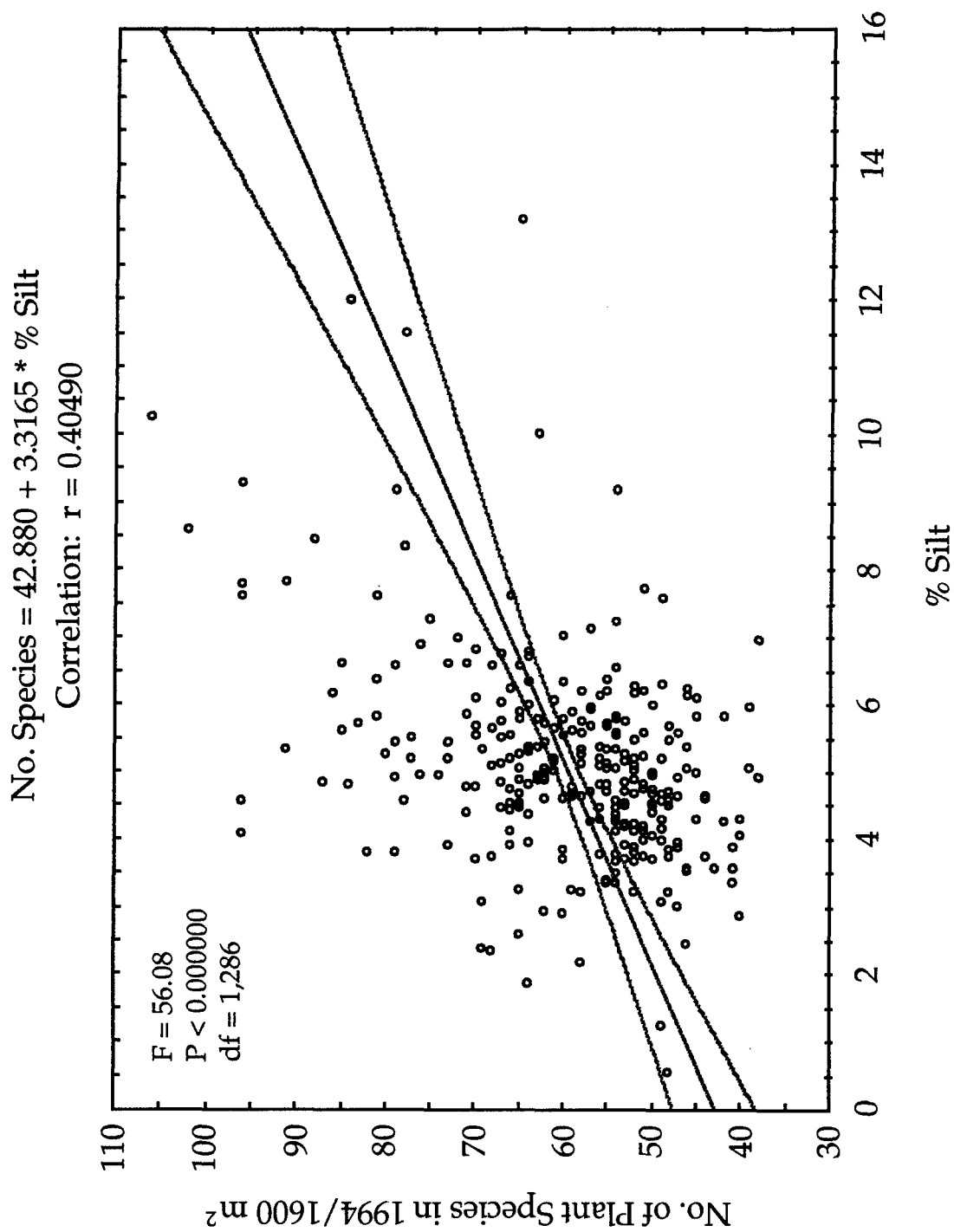


Fig. 2.8. Regression of the number of plant species sampled in 1994 against percent silt from pre-treatment restoration, reference, and sand pine removal 81-ha (200-acre) plots at EAFB, Florida. The 95% confidence interval is presented with the regression line.

Table 2.1. Soil texture classes (± 1 standard error) of soil samples from restoration, reference, and sand pine removal plots at Eglin Air Force Base, Florida. Samples were collected from eight randomly chosen 10×40 -m subplots per 81-ha (200-acre) plots. Sample sizes were: 32 subplots per restoration block (4 plots); 16 subplots per reference block (2 plots); and 8 subplots per sand pine removal plot.

Plot	% Sand classes (mm)						% Total sand	% Silt	% Clay	
	4.0	2.0	0.5	0.25	0.125	0.0623				
Restoration										
F ₁	0.006 ± 0.006	0.015 ± 0.004	33.345 ± 1.1	48.767 ± 0.6	15.254 ± 0.8	2.614 ± 0.11	92.21 ± 0.3	5.479 ± 0.26	2.245 ± 0.06	
F ₂	0.000 ± 0.000	0.062 ± 0.020	31.420 ± 1.5	50.228 ± 0.7	15.432 ± 0.9	2.858 ± 0.23	92.63 ± 0.2	5.281 ± 0.17	2.020 ± 0.08	
F ₃	0.000 ± 0.000	0.009 ± 0.004	27.082 ± 0.9	56.210 ± 0.6	14.728 ± 0.4	1.971 ± 0.12	92.62 ± 0.1	5.028 ± 0.14	2.305 ± 0.06	
F ₄	0.000 ± 0.000	0.004 ± 0.002	24.796 ± 0.7	56.799 ± 0.3	16.241 ± 0.6	2.160 ± 0.12	92.96 ± 0.1	4.793 ± 0.11	2.198 ± 0.05	
F ₅	0.000 ± 0.000	0.064 ± 0.036	21.316 ± 1.8	56.630 ± 1.4	19.160 ± 0.7	2.831 ± 0.16	93.70 ± 0.2	4.197 ± 0.20	2.047 ± 0.08	
F ₆	0.025 ± 0.019	0.141 ± 0.075	21.306 ± 1.1	56.920 ± 1.0	18.499 ± 0.7	3.109 ± 0.35	92.88 ± 0.2	4.646 ± 0.26	2.425 ± 0.15	
Reference										
R ₁	0.000 ± 0.000	0.104 ± 0.022	60.146 ± 2.2	32.309 ± 1.9	5.596 ± 0.3	1.845 ± 0.14	92.31 ± 0.1	5.366 ± 0.14	2.263 ± 0.08	
R ₂	0.089 ± 0.089	1.265 ± 0.280	38.757 ± 3.6	37.704 ± 2.4	17.835 ± 2.1	4.350 ± 0.75	88.63 ± 0.6	8.770 ± 0.56	2.495 ± 0.23	
R ₃	0.000 ± 0.000	0.087 ± 0.063	30.099 ± 2.9	51.149 ± 2.3	15.513 ± 1.0	3.151 ± 0.28	92.34 ± 0.3	5.215 ± 0.26	2.422 ± 0.12	
Sand pine removal										
S ₁	0.000 ± 0.000	0.263 ± 0.068	26.284 ± 1.0	49.345 ± 1.1	20.178 ± 0.8	3.930 ± 0.24	91.06 ± 0.4	6.535 ± 0.37	2.339 ± 0.11	
S ₂	0.000 ± 0.000	0.005 ± 0.002	25.255 ± 0.9	55.124 ± 0.5	18.057 ± 0.7	1.560 ± 0.16	93.30 ± 0.2	4.230 ± 0.19	2.465 ± 0.09	
S ₃	0.000 ± 0.000	0.002 ± 0.001	18.358 ± 2.3	63.329 ± 1.0	17.149 ± 1.4	1.162 ± 0.09	93.67 ± 0.1	4.033 ± 0.18	2.310 ± 0.16	
S ₄	0.000 ± 0.000	0.004 ± 0.002	14.709 ± 1.4	54.453 ± 2.1	28.159 ± 1.9	2.675 ± 1.16	92.38 ± 0.4	5.550 ± 0.32	2.063 ± 0.17	
S ₅	0.000 ± 0.000	0.126 ± 0.050	24.694 ± 1.0	45.647 ± 1.1	25.713 ± 1.2	3.821 ± 0.39	93.20 ± 0.2	4.326 ± 0.40	2.456 ± 0.32	
S ₆	0.000 ± 0.000	0.297 ± 0.254	32.110 ± 3.1	32.953 ± 2.6	31.179 ± 3.8	3.461 ± 0.68	93.29 ± 0.4	4.381 ± 0.24	2.325 ± 0.20	

Table 2.2. Soil chemistry variables (± 1 standard error) of soil samples from restoration, reference, and sand pine removal plots at Eglin Air Force Base, Florida. All elements have units of mg per kg of soil, and organic matter is expressed as a percent of soil weight. Samples were collected from eight randomly chosen 10×40 -m subplots per 81-ha (200-acre) plots. Sample sizes were: 32 subplots per restoration block (4 plots); 16 subplots per reference block (2 plots); and 8 subplots per sand pine removal plot.

Plot	pH	Ca (mg/kg)	Mg (mg/kg)	K (mg/kg)	P (mg/kg)	Al (mg/kg)	Fe (mg/kg)	Na (mg/kg)	Cl (mg/kg)	OM† %	TKN‡ (mg/kg)
Restoration											
F ₁	4.56 \pm 0.03	16.66 \pm 2.75	2.99 \pm 0.12	4.38 \pm 0.16	1.36 \pm 0.05	142.71 \pm 4.39	22.01 \pm 0.63	6.05 \pm 0.32	5.42 \pm 0.41	0.73 \pm 0.04	203.91 \pm 4.64
F ₂	4.54 \pm 0.01	12.40 \pm 0.94	2.92 \pm 0.18	4.91 \pm 0.17	1.30 \pm 0.02	129.25 \pm 3.03	22.69 \pm 0.37	6.21 \pm 0.37	4.12 \pm 0.55	0.63 \pm 0.02	184.66 \pm 3.46
F ₃	4.71 \pm 0.02	25.38 \pm 5.31	3.21 \pm 0.11	4.99 \pm 0.17	1.51 \pm 0.14	145.46 \pm 3.55	21.86 \pm 0.48	6.16 \pm 0.26	4.35 \pm 0.51	0.75 \pm 0.02	230.46 \pm 4.41
F ₄	4.71 \pm 0.03	15.80 \pm 0.69	3.16 \pm 0.13	4.94 \pm 0.19	1.30 \pm 0.03	135.81 \pm 3.05	19.98 \pm 0.39	7.37 \pm 0.29	4.69 \pm 0.25	0.68 \pm 0.03	261.58 \pm 16.21
F ₅	4.60 \pm 0.02	12.73 \pm 0.48	2.88 \pm 0.07	4.77 \pm 0.15	1.50 \pm 0.04	135.38 \pm 2.57	22.26 \pm 0.60	4.78 \pm 0.36	3.39 \pm 0.63	0.80 \pm 0.03	202.67 \pm 5.03
F ₆	4.70 \pm 0.03	14.53 \pm 0.79	3.16 \pm 0.12	5.12 \pm 0.19	1.66 \pm 0.12	136.66 \pm 2.99	22.06 \pm 0.45	5.19 \pm 0.33	3.33 \pm 0.12	0.80 \pm 0.02	264.55 \pm 10.48
Reference											
R ₁	4.69 \pm 0.03	19.39 \pm 2.73	3.27 \pm 0.13	4.97 \pm 0.20	1.36 \pm 0.04	154.03 \pm 7.14	22.66 \pm 0.60	7.42 \pm 0.32	3.59 \pm 0.37	0.84 \pm 0.04	259.28 \pm 6.90
R ₂	4.75 \pm 0.02	15.96 \pm 0.93	3.54 \pm 0.21	5.68 \pm 0.21	1.38 \pm 0.11	163.98 \pm 17.73	22.41 \pm 0.60	9.44 \pm 0.52	3.03 \pm 0.14	0.72 \pm 0.03	187.50 \pm 9.75
R ₃	4.81 \pm 0.06	17.86 \pm 1.83	3.21 \pm 0.22	4.94 \pm 0.28	1.43 \pm 0.06	154.38 \pm 5.59	23.93 \pm 0.85	7.30 \pm 0.57	4.74 \pm 0.52	0.94 \pm 0.02	251.84 \pm 16.44
Sand pine removal											
S ₁	4.62 \pm 0.02	15.95 \pm 1.23	3.81 \pm 0.20	6.31 \pm 0.36	1.68 \pm 0.05	157.84 \pm 2.82	23.96 \pm 0.51	7.01 \pm 0.35	2.86 \pm 0.24	1.18 \pm 0.25	212.50 \pm 6.53
S ₂	4.59 \pm 0.02	15.23 \pm 0.78	3.40 \pm 0.16	5.15 \pm 0.23	1.51 \pm 0.04	158.13 \pm 5.77	23.61 \pm 0.76	6.22 \pm 0.39	2.58 \pm 0.32	0.51 \pm 0.03	196.56 \pm 4.15
S ₃	4.61 \pm 0.04	14.11 \pm 0.63	3.15 \pm 0.19	4.36 \pm 0.18	1.29 \pm 0.09	156.31 \pm 7.90	26.73 \pm 1.40	4.25 \pm 0.19	1.93 \pm 0.39	0.60 \pm 0.03	191.34 \pm 8.09
S ₄	4.50 \pm 0.03	15.00 \pm 1.34	3.59 \pm 0.11	5.36 \pm 0.14	1.80 \pm 0.13	218.78 \pm 18.36	25.78 \pm 0.64	4.72 \pm 0.26	1.94 \pm 0.22	1.01 \pm 0.10	222.91 \pm 10.37
S ₅	4.38 \pm 0.02	10.54 \pm 0.74	2.87 \pm 0.18	4.18 \pm 0.24	1.35 \pm 0.03	126.84 \pm 1.48	24.91 \pm 0.52	4.47 \pm 0.20	3.55 \pm 0.44	0.71 \pm 0.03	166.56 \pm 3.90
S ₆	4.67 \pm 0.03	17.24 \pm 1.43	3.34 \pm 0.22	5.21 \pm 0.30	1.46 \pm 0.06	154.00 \pm 4.51	22.56 \pm 0.63	7.82 \pm 3.30	3.44 \pm 1.79	0.79 \pm 0.03	232.69 \pm 13.80

† OM = Organic matter content.

‡ TKN = Total Kjeldahl N.

Table 2.3a. Correlations among the depth of the argillic horizon and the slope of the auger sample location versus soil organic matter, total Kjeldahl N, and soil texture classes for a subset of the data that only contained Troup soil (i.e., depth of the argillic horizon <2.0 m). Sample size = 11. Significant correlations (>0.6 or <-0.6) are in boldface.

Variable	Depth of argillic horizon	Slope
Organic matter content	0.09	0.03
Total Kjeldahl N	0.19	-0.01
% Sand classes (mm)		
2.0	0.29	-0.39
0.5	0.38	-0.01
0.25	-0.41	0.24
0.125	-0.22	-0.19
0.063	0.14	-0.52
% Total sand	-0.32	0.60
% Silt	0.38	-0.58
% Clay	-0.28	-0.39

Table 2.3b. Correlations among the depth of the argillic horizon and the slope of the auger sample location versus soil organic matter, total Kjeldahl N, and soil texture classes for the full data that contained Troup and Lakeland soils. Sample size = 288. Significant correlations (>0.11 or <-0.11) are in boldface.

Variable	Depth of argillic horizon	Slope
Organic matter content	-0.08	0.06
Total Kjeldahl N	0.02	-0.01
% Sand classes (mm)		
2.0	-0.07	-0.09
0.5	0.05	-0.24
0.25	0.04	0.12
0.125	-0.14	0.27
0.063	-0.05	0.05
% Total sand	0.08	0.29
% Silt	-0.06	-0.24
% Clay	-0.07	-0.19

Table 2.4. Correlations between the number of plant species ($\log[X+1]$ -transformed) sampled in the fall 1994 and soil texture variables. Sample size = 288. Only significant correlations (>0.11 or <-0.11) are presented.

Soil texture	Log(No. plant species)
% Sand classes (mm)	
2.0	0.34
0.5	0.21
0.25	-0.25
0.125	
0.063	0.24
% Total sand	-0.38
% Silt	0.39

Table 2.5a. Correlations among soil chemistry variables and common groundcover plant species densities and tree species basal area. Only significant correlations are presented. Sample size = 288.

Species	pH	Ca	Mg	K	P	Al	Fe	Na	Cl	OM†	TKN‡
Groundcover species											
<i>Andropogon virginicus</i>	0.22					0.16		0.28			
<i>Aristida beyrichiana</i>	0.17		0.17	0.14		0.25			-0.15		
<i>Aristida purpurescens</i>					0.13						0.15
<i>Crataegus lacrimata</i>					0.18			-0.23			
<i>Croton argyranthemus</i>										-0.13	
<i>Dichanthelium</i> spp.	0.21	0.18	0.15			0.31		0.17			
<i>Eupatorium compositifolium</i>	0.15		0.14					0.13		0.21	0.17
<i>Galactia floridana</i>					-0.13			0.13		-0.17	
<i>Gaylussacia dumosa</i>	-0.15		-0.15	-0.17	-0.22	-0.16				-0.25	-0.34
<i>Liatris</i> spp.					-0.18			0.27			-0.17
<i>Licania michauxii</i>											
<i>Pinus palustris</i>	-0.16				-0.13			0.15			
<i>Pityopsis aspera</i>								0.22			-0.14
<i>Pityopsis graminifolia</i>			0.20	0.24				0.32			
<i>Polygonella gracilis</i>		-0.13	-0.18	-0.19	-0.19				0.16		-0.16
<i>Pteridium aquilinum</i>						-0.14	-0.17			-0.17	
<i>Quercus geminata</i>				0.15							
<i>Schizachyrium scoparium</i>	0.16							0.21		-0.18	-0.13
<i>Smilax auriculata</i>	-0.29								0.33	-0.16	-0.17
<i>Solidago odora</i>			0.15	0.20				0.33	-0.15	0.16	-0.13
<i>Sorghastrum secundum</i>							0.14	0.17			0.18
<i>Vaccinium darrowii</i>								0.16			-0.22
Tree species											
<i>Diospyros virginiana</i>									0.15		
<i>Ilex vomitoria</i>	-0.27								0.21		
<i>Pinus palustris</i>		0.14	0.20		-0.13	0.33		0.29	0.14		
<i>Quercus geminata</i>	-0.14							-0.16			
<i>Quercus incana</i>				0.13		-0.18	-0.17	-0.15		-0.14	
<i>Quercus laevis</i>	-0.18					-0.25		-0.15			
<i>Quercus margareta</i>		0.14	0.14	0.15	0.22					0.21	0.20

† OM = Organic matter content.

‡ TKN = Total Kjeldahl N.

Table 2.5b. Correlations among soil texture and common groundcover plant species densities and tree species basal area. Only significant correlations are presented. Sample size = 288.

Species	% Sand classes (mm)					% Sand	% Silt	% Clay
	2.0	0.5	0.25	0.125	0.063			
Groundcover species								
<i>Andropogon virginicus</i>		0.47	-0.47	-0.38		-0.23	0.23	
<i>Aristida beyrichiana</i>			-0.32	0.21	0.34	-0.54	0.54	0.18
<i>Aristida purpurescens</i>			0.17			0.18	-0.22	
<i>Crataegus lacrimata</i>	-0.26	0.21	0.23			0.17	-0.15	
<i>Croton argyranthemus</i>	0.24	-0.21	-0.18			-0.20	0.15	
<i>Dichanthelium</i> spp.	0.18	-0.26			0.16	-0.31	0.30	
<i>Eupatorium compositifolium</i>	0.33	-0.34	-0.27			-0.15	0.14	
<i>Galactia floridana</i>	0.27	-0.23	-0.26					
<i>Gaylussacia dumosa</i>	0.13						0.19	
<i>Liatris</i> spp.	0.26	-0.36			0.15	-0.38	0.34	
<i>Licania michauxii</i>	0.26	-0.15	-0.32		-0.13			
<i>Pinus palustris</i>	0.51	-0.46	-0.45					
<i>Pityopsis aspera</i>	0.32	-0.43	-0.13		0.19	-0.37	0.37	0.13
<i>Pityopsis graminifolia</i>	0.15	-0.34			0.27	-0.48	0.44	
<i>Polygonella gracilis</i>					0.17	0.14		
<i>Pteridium aquilinum</i>	-0.21	0.23						
<i>Quercus geminata</i>			-0.18	0.21	0.25	-0.29	0.25	
<i>Schizachyrium scoparium</i>	0.30	-0.30	-0.20			-0.28	0.26	
<i>Smilax auriculata</i>	-0.21	0.24	0.18			0.17		
<i>Solidago odora</i>	0.41	-0.52	-0.19		0.17	-0.42	0.41	0.15
<i>Sorghastrum secundum</i>	0.25		-0.36		-0.25			
<i>Vaccinium darrowii</i>	0.27	-0.33			0.16	-0.38	0.36	
Tree Species								
<i>Diospyros virginiana</i>	0.16						-0.16	
<i>Ilex vomitoria</i>								
<i>Pinus palustris</i>		0.33	-0.41	-0.13		-0.39	0.41	
<i>Quercus geminata</i>	0.14	-0.17		0.20				
<i>Quercus incana</i>		-0.23	0.33		-0.18			
<i>Quercus laevis</i>		-0.30	0.38		-0.17	0.34	-0.36	
<i>Quercus margaretta</i>								

3. INITIAL EFFECTS OF HARDWOOD REDUCTION TECHNIQUES ON PLANTS IN SANDHILLS AT EGLIN AIR FORCE BASE, FLORIDA

ABSTRACT

Restoring fire-suppressed sandhill communities often includes reducing hardwood structure and increasing herbaceous cover. Using a complete randomized block design, we compared the initial effects of three hardwood reduction techniques (growing season burning, herbicide [ULW[®] form of hexazinone] application, chainsaw felling/girdling) and no-treatment control on measures of plant species richness, cover groups and life forms, and species densities in fire-suppressed sandhills at Eglin Air Force Base, Florida. Restoration treatments significantly decreased canopy cover compared to the control in 1995 and 1996. Canopy cover was decreased the least in burn plots and most in felling/girdling plots. Fire achieved only partial hardwood topkill. Longleaf pine (*Pinus palustris*) seedling and sapling densities (<1.4 m high) decreased in all plots from 1994/95 to 1995/96 and showed little to no decline from 1995/96 to 1996/97; however, this decrease was significantly greater only in burn plots (almost 50% in 1995). A total of 349 plant taxa in seventy-two families, and 187 genera were documented in the restoration and reference plots from spring 1994 until fall 1996. In 1995, plant species richness was not significantly different among treatments. In 1996, plant richness was significantly higher in burn plots than in other treatments. By fall 1996, we found that treatments had no significant effects on the densities of many common groundcover species. However, low panic grasses (*Dichanthelium* spp.) responded positively to fire, and pineywoods dropseed (*Sporobolus junceus*) and wireweed (*Polygonella gracilis*) showed moderately negative responses to fire. We also noted that low panic grasses, Gray's beakrush (*Rhynchospora grayi*), pineywoods dropseed, and gopher apple (*Licania michauxii*) decreased most in the ULW[®] plots, while lopsided Indian grass (*Sorghastrum secundum*) and yellow stargrass (*Hypoxis juncea*) increased in these plots. Low panic grasses and gopher apple also responded positively to felling/girdling. Prescribed burning was the least expensive (approximately \$5/acre or \$12/ha) treatment to apply. Fire significantly stimulated plant species richness, but also significantly reduced longleaf pine seedling densities and, while significant, did not effectively reduce canopy cover. Both ULW[®] and felling/girdling were more expensive (approximately \$40/acre or \$99/ha), but effectively reduced the hardwood midstory. Felling/girdling achieved the greatest midstory reduction. Felling/girdling had mostly positive and neutral effects. With the exception of longleaf pine seedlings and saplings, ULW[®] effects were often negative with respect to understory plants. Continued sampling will test these patterns over several years.

INTRODUCTION

Historical Distribution and Ecology. Since European settlement, and especially in the last century, the longleaf pine (*Pinus palustris*) landscape has been reduced by as much as 98%, primarily due to clearing for agriculture, conversion to other pine types, and urban development (Noss 1989, Myers 1990). Open-canopied longleaf pine forests once covered an estimated 37.5 million ha (92.5 million acres) in the southeastern U.S. (Frost 1993) and were characterized by some of the highest plant species richness in North America (Walker and Peet 1983, Hardin and White 1989, Walker 1993). A 1995 study (Landers et al. 1995) estimates that only 1.3 million ha (3.2 million acres) of longleaf pine stands remain, of which most are second-growth, even-aged, fragmented, and isolated. This community has been degraded by past logging, turpentine, grazing, and disruption of natural fire regimes (Means and Grow 1985, Noss 1988, Frost 1993). Remaining old growth stands are primarily small relics (<25 acres) that have also experienced extensive grazing, altered fire regimes, and selective logging.

Therefore, restoration of remaining impaired longleaf pine forests has become a high conservation priority.

Longleaf pine was once found from Virginia to Texas along the Atlantic and Gulf of Mexico coasts and extended northward into Alabama and Mississippi (Frost 1993, Landers et al. 1995, Plunkett and Hall 1995). A recent historical analysis of Public Lands Survey records for north Florida (Schwartz 1994) suggests that pre-settlement and early post-settlement upland landscapes were overwhelmingly dominated by yellow pines, most likely longleaf pine, rather than by mixed hardwood vegetation. Both written and photographic historical accounts characterize intact old-growth longleaf pine landscapes as having an open canopy consisting of scattered large individual pines, clumps of younger pines, scattered oaks and hardwoods of various ages and sizes, and a low groundcover of shrubs, mixed forbs, and grasses (often wiregrass [*Aristida beyrichiana*, *A. stricta* of earlier authors]) (e.g., Means and Grow 1985, Platt, Evans, and Davis 1988, Hardin and White 1989, Myers 1990).

Understory plant communities of longleaf pine forests vary geographically (Harcombe et al. 1993, Peet and Allard 1993). The majority of longleaf pine ecosystems in both xeric and mesic conditions from North Carolina to Mississippi are dominated by two species of wiregrass: *Aristida stricta* and *A. beyrichiana* (Peet 1993, Peet and Allard 1993). Both species are generally restricted to the lowlands along the Gulf Coast. *Aristida stricta* occurs throughout North Carolina in north-eastern South Carolina. Both *Aristida stricta* and *A. beyrichiana* are absent from central South Carolina stands (Peet 1993). *Aristida beyrichiana* ranges from the southern portion of South Carolina, south throughout the Florida peninsula, and west to the southern-most portions of Mississippi (Peet 1993). In extreme western Florida at Eglin Air Force Base (EAFB) there are large areas of *Aristida beyrichiana* (FNAI [Florida Natural Areas Inventory] 1995, Provencher et al. 1996, Rodgers and Provencher, *in press*). Further west of Florida, *Aristida beyrichiana* is progressively replaced by bluestem grasses such as little bluestem (*Schizachyrium scoparium*), slender bluestem (*S. tenerum*), silver bluestem (*Andropogon ternarius*) and other grasses, such as pineywoods dropseed (*Sporobolus junceus*) and several low panic grasses (*Dichanthelium* spp.) (reviewed in Harcombe et al. 1993). Several common forbs from western longleaf pine forests were found to be well represented in eastern forests (Harcombe et al. 1993). Examples of these wide-ranging species include grass-leaf golden aster (*Pityopsis graminifolia*), stiff-leaved aster (*Aster linariifolius*), erect milk-pea (*Galactia erecta*), and dollar weed (*Rhynchosia reniformis*). Preliminary vegetation analysis of EAFB suggests that herbaceous composition is transitional between the eastern longleaf pine/wiregrass and western longleaf pine/bluestem communities (Provencher et al. 1996, Rodgers and Provencher, *in press*).

The longleaf pine ecoregion is composed of some of the most species rich plant communities in North America (Hardin and White 1989). Atlantic coastal plain longleaf pine forests are especially notable for their high species richness at small spatial scales (Walker and Peet 1983, Huston 1994). For example, Walker and Peet (1983) reported species richness of up to 42 species/0.25 m² and 82 species/625 m² in mesic longleaf pine-wiregrass stands from the Green Swamp of North Carolina, representing the highest species richness estimates for North American plant assemblages (at small scales). At a larger spatial scale, Provencher et al. (1996) recorded >260 species of plants from 36 subsampled 20-ha (50-acre) plots in xeric sandhills at EAFB in 1994. Richness varied from 62-123 species/12800 m² in fire-suppressed and variously disturbed plots and from 77-154 species/12800 m² in frequently-burned sandhills of variable soil disturbance. Large numbers of rare and endemic species are also associated with various longleaf pine communities. Walker (1993) reported that 187 rare vascular plant taxa, of which 96 are endemic, are associated with longleaf pine throughout its range. At EAFB, 18 rare, threatened, endemic, or endangered plant species have been documented in longleaf pine communities (FNAI 1994 and 1995, Kindell et al. 1997, Provencher et al. 1996 and 1997, Rodgers and Provencher, *in press*).

Restoration Issues and Techniques. Restoration of the regional longleaf pine landscape presents significant management challenges, particularly where fire has been suppressed or excluded for many years and/or where groundcover has been heavily disturbed. Fire-suppressed stands may be difficult to burn under hot, but effective restoration prescriptions because heavy midstory fuel loads can damage the longleaf pine canopy. On the other hand, cool, but cautious fire prescriptions may not topkill hardwoods (Myers 1993). Heavily disturbed herbaceous understories may require native plant restoration, which is expensive and still experimental, or long recovery periods (Provencher et al. 1997, Rodgers and Provencher, *in press*). These problems are especially acute for managers of large public holdings, where thousands of hectares may require extensive restoration.

Despite the challenges associated with the restoration of large areas of longleaf pine landscape, the potential for success is promising. Simberloff (1993) suggested that these ecosystems have a high restoration potential due to their structural simplicity, the existence of second growth stands, and the physical characteristics of open longleaf forests which may permit limited resource acquisition without serious perturbation of ecosystem function. Myers (1993) has outlined longleaf pine community restoration (using prescribed fire) based on the following objectives: a) ensure survival of existing longleaf pine; b) reduce accumulated litter; c) reduce numbers of hardwood trees and shrubs; d) prepare the longleaf pine seedbed; e) ensure longleaf pine seedling survival; and f) stimulate understory growth, flowering and diversity. Although hardwood reduction is the critical first step to successful restoration, preservation and enhancement of native groundcover flora and fauna must be considered through the entire restoration process, as they represent the majority of biodiversity in sandhill systems.

In addition to Myers' (1993) suggested approach to restoration, we emphasize the importance of landscape-level restoration that returns functionality to a system characterized by ecological processes and species with large-scale domains (e.g., fire, hurricanes, red-cockaded woodpecker [*Picoides borealis*], and black bear [*Ursus americanus*]) (Holling 1992, Gordon et al. 1997). Addressing the anthropogenic constraints (e.g., forest fragmentation) imposed on species and ecological processes involves recoupling life history traits and the factors that shape them. However, the cost of large-scale restoration may limit management options, and we stress the need to study the trade-off between restoration effort and ecological outcomes.

Several methods of pineland restoration through hardwood reduction have been implemented or proposed, including fire, herbicides, mechanical felling, and fuel chipping, but little quantitative information on the efficacy and ecological consequences of these methods is available. We review here several of these techniques.

As the predominant natural disturbance of longleaf pine ecosystems, fire is likely to be the most ecologically consistent method of restoring ecosystem function and structure to fire-suppressed sandhills. Fire is important in both the establishment and survivorship of longleaf pine by: a) providing a suitable substrate for seedlings to sprout and grow; b) controlling principal foliar disease as brown-spot needle blight; and c) reducing competition by shrubs and hardwoods (Rebertus et al. 1989a). The effectiveness of early growing season burns on hardwood canopy reduction in longleaf pine forests is now widely accepted (Grano 1970, Grelen 1975, Boyer 1990, Streng et al. 1993, Glitzenstein et al. 1995). Moreover, oak recruitment following early growing season burns is significantly less than that of fire in other seasons (Glitzenstein et al. 1995). Interestingly, neither oak mortality nor regeneration appears to be significantly affected by variation in fire behavior (e.g., maximum fire temperature) or fire return interval (e.g., annual versus biennial) (Rebertus et al. 1993, Streng et al. 1993). Where severely fire-suppressed sites can carry fire, early growing season burns should be an effective, low cost method of hardwood reduction. In a 43-year experiment, White et al. (1991) found that woody species richness increased in periodic winter burn treatments compared to the no-burn control, but decreased in all other combinations of frequency and season of burn.

Longleaf pine response to fire can be highly variable depending on the season, fire duration and intensity, and ambient air temperature and humidity (Grelen 1975, Boyer 1990 and 1993, Platt et al. 1991, Glitzenstein et al. 1995). While results of fire seasonality studies have varied, both longleaf pine trees and seedlings appear to respond most favorably to early growing-season burns (Grelen 1978, Maple 1977, Robbins and Myers 1992). However, more recent studies have reported longleaf pine dynamics to be better predicted by variation in fire behavior than by season of burn, although in both cases the effects are weak relative to hardwood responses (Rebertus et al. 1993, Glitzenstein et al. 1995). This pattern generally holds true for understory vegetation. Growing season fire increases herbaceous biomass (Lewis and Harshbarger 1976), herbaceous species richness (White et al. 1991), and flowering and seed production (Parrot 1967; Abrahamson 1984; Platt, Evans, and Davis 1988), although fire intensity may contribute significantly to understory plant responses as well.

Hence, an increasing body of evidence suggests that in the presence of sufficient fuels, prescribed fire is the most effective and least expensive long-term maintenance tool for upland longleaf pine systems (reviewed in Robbins and Myers 1992). However, elevated fuel loads and fuel ladders resulting from decades of fire suppression may initially cause especially intense fires that negatively affect non-target elements of the community (e.g., mature longleaf pine, sparse understory vegetation). Alternatively, the suppression of groundcover vegetation and accumulation of fire-resistant litter often results in cool or patchy fires, insufficient or patchy mortality of target species, and insufficient release of desired species. Thus, use of fire as an initial restoration tool may give inconsistent results in severely fire-suppressed sandhills. Alternate restoration methods alone or in combination with prescribed burning may be necessary where reintroduction of fire is difficult. Few studies are available to suggest which methods or combinations will yield the desired community level restoration results.

Herbicides, particularly hexazinone [3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4 (1H,3H)-dione] (E. I. DuPont de Nemours and Company, Wilmington, DE), are often used to reduce oak densities. Hexazinone has little or no direct effect on pines (cited in Wilkins et al. 1993), but may induce mortality rates approaching 100% among certain oak species (Minogue et al. 1988, Wilkins et al. 1993). Berish (1996) reported average oak mortality of 54% with the granular form of hexazinone (ULW[®]) and 40% with brushbullet (Pronone[®]) at EAFB. Evidence suggests that hardwood reductions caused by hexazinone result in increases in abundance of at least some understory species (Duever 1989, Brooks et al. 1993). However, species diversity also has been shown to decrease with slightly higher application rates on sandhill communities (Wilkins et al. 1993). Moreover, the granular form of hexazinone (ULW[®]) is recommended for control of herbaceous plants such as broomsedge (*Andropogon virginicus*), dog fennel (*Eupatorium compositifolium*), goldenrods (*Solidago* spp.), and the non-oak hardwood *Prunus* spp., flowering dogwood (*Cornus florida*), and other local natives at rates comparable to those used for oak control.

While promising, hexazinone's expense (estimated at \$100/ha or \$40/acre, including labor), high soil solubility, potential mobility in deep sands (Neary et al. 1983), and potential effects on many sandhill plant (Wilkins et al. 1993) and animal species, warrant caution in its widespread use. These potentially negative aspects are of special concern at EAFB given the large areas requiring restoration and the presence of numerous creek systems with associated rare fauna (e.g., federally listed Okaloosa darter [*Etheostoma okaloosae*]) and flora (FNAI 1995, Kindell et al. 1997).

Other hardwood reduction techniques used at EAFB fall under the general categories of: 1) midstory reduction through mechanical means and 2) site preparation for longleaf pine regeneration. These include one or more of the following techniques: felling or girdling using chainsaws; rubber-tired skidders for removing fallen trees to loading decks; use of rubber-tired feller-bunchers; and roller drum chopping (and related root raking, disking, and double-bedding).

Mechanical felling/girdling of hardwood trees is the most immediate method of reducing hardwood stand structure. While resprouting of felled trees would be rapid, subsequent burning of the site should constrain hardwood recovery. The marked increases in resources (e.g., light and soil moisture) should affect the minimally impacted understory and pines. Few studies have examined the effect of hardwood felling on soil chemistry in the Southeast. Boyer and Miller (1994) have shown that felling of woody species significantly increased available soil nitrogen and phosphorus within one year of application compared to no-clearing and/or burning. This is likely due to increased nutrient inputs (Johnson et al. 1985) and soil moisture retention (Boyer and Miller 1994) from organic matter (woody) residues.

While hand-felling or girdling results in the least amount of soil and vegetation disturbance, several potential drawbacks remain. The large accumulation of fuels at the understory level may support high intensity, slow moving fires that kill remaining longleaf pine and understory vegetation during subsequent burns. Moreover, hand-felling across large areas is labor intensive and costly (at least \$100/ha or \$40/acre). Given the proper market conditions and quantity of wood available on site, either sand pine (*Pinus clausa*) or hardwood removal could be done on a commercial basis. Assuming that harvesting techniques minimize, but do not eliminate damage to native vegetation, restoration may pay for itself.

EAFB may have the largest longleaf pine holdings in public ownership ($\geq 144,000$ ha or 360,000 acres) (Outcalt and Outcalt 1994). These old-growth forests include the Patterson Natural Area (≥ 371 ha or 928 acres) and adjoining forests (>400 ha or 1000 acres of the Patterson Extension Area and forests west of there) (FNAI 1995, Provencher et al. 1996, Kindell et al. 1997). Many land management issues about the maintenance and restoration of longleaf pine-dominated sandhill communities are relevant at EAFB. Hardwood and sand pine encroachment, suppressed or disturbed herbaceous groundcover, lack of sufficient fine fuels, and/or extensive forest fragmentation are significant problems at EAFB (DoD-Air Force 1993).

Research Objectives. In order to address these issues, we experimentally compared the initial effects of three hardwood reduction techniques in fire-suppressed sandhills (growing season burn, ULW[®] form of herbicide, and midstory mechanical felling/girdling) and a no-treatment control on tree densities and basal areas. Different measures of understory vegetation within the treatments and controls were also compared. Treated sandhills were contrasted to frequently-burned longleaf pine-dominated sandhills, which were not part of the experimental design. Results presented here are from the first three years of the study. We examined data collected during the 1994 pre-treatment phase and during the 1995 and 1996 fall seasons following treatment application.

We predicted that the herbicide treatment would decrease canopy cover, woody midstory and understory species (primarily oaks), and some herbaceous species, therefore reducing species richness. Release of soil nutrients from fine roots and microorganisms and increased sunlight at the groundcover level would stimulate herbaceous plant growth. Prescribed growing season burning was expected to trigger a vigorous regrowth and flowering of grasses and some forbs. We did not expect as dramatic a reduction in canopy cover as predicted in ULW[®] plots because fire generally does not topkill all hardwoods (Glitzenstein et al. 1995). Contrary to the condition in ULW[®] plots, fine litter should be combusted and bare ground exposed in burn plots. Except for the very predictable increase in woody litter and decrease in canopy cover from chainsaw felling, we did not expect any initial vegetation changes in these plots compared to controls during the first year. However, leaching of nutrients from slash and increased sunlight should stimulate plant growth during the subsequent years.

SITE DESCRIPTION

EAFB occupies the southern portions of Walton, Okaloosa, and Santa Rosa counties in the western Florida Panhandle (Fig. 3.1). EAFB is bordered by the Yellow River and Alaqua

Creek to the north and east and by the Gulf of Mexico and Choctawhatchee Bay to the south and east. Sandhill sites selected for this study varied in degree of past fire frequency, soil alteration, and groundcover dominants.

With a historically high fire frequency (approximately 1-10 years), the longleaf pine sandhill community is characterized by a nearly pure open overstory of longleaf pine, a sparse midstory of hardwoods (oaks and others), and a diverse groundcover dominated by native perennial graminoids and forbs (Myers 1990). Following extended periods of fire suppression, a dense midstory of oaks and other hardwood tree species develops, and groundcover of graminoids and forbs significantly decreases (White et al. 1991, Robbins and Myers 1992). Fire suppression also results in increased importance of medium statured shrubs (e.g., blueberries [*Vaccinium* spp.]) and woody vines (e.g., catbriers [*Smilax* spp.]) in the midstory. Both historic and present day forestry and military activities have resulted in significant soil alteration across EAFB. Herbaceous species composition and richness is altered when soil is disturbed (Rodgers and Provencher, *in press*). Earth mining, tank activity, roads, clearcuts, selective timber harvesting, stumping, fire breaks, and other activities now create a mosaic of disturbances in both fire-suppressed and frequently-burned longleaf pine stands at EAFB.

The climate is temperate with mild winters and hot, humid summers. Winters tend to be somewhat milder near the coast compared to the inland regions (Chen and Gerber 1990). The mean annual temperature is 18.3° C, with approximately 275 freeze-free days per year. Thunderstorms and lightning strikes are frequent during the summer months. Mean annual precipitation is 158 cm per year (DoD-Air Force 1995). Monthly precipitation levels peak slightly during late spring and early summer months and decrease during the winter months. Snow accumulation is rare. Tropical storms are frequent along the Gulf Coast of Florida and neighboring states. Between 1871 and 1985, 115 tropical storms and hurricanes made landfall within 110 km of EAFB (NOAA 1994).

The terrain is level to gently rolling with occasional areas of steeply inclined terrain. Elevation ranges from 0-100 m above sea levels and the landscape generally slopes to the southwest toward the Gulf of Mexico. The Citronelle Formation (Pleistocene-aged) is the dominant parent material for the surficial sediments (Overing et al. 1995). It consists of sand, clay, and gravel with occasional limonite beds, lenses, and pavements. Between the surficial layers and the parent material, there is often a one to two meter zone of red, silty or clayey sand. The relative depth and density of this silty zone can significantly alter soil moisture availability to groundcover plant species. Apparently, the depth of this zone is independent of elevation or proximity to the coastline (Clark and Schmidt 1982).

Throughout most EAFB sandhills, the Lakeland soil series is the common surficial soil. This series is a thermic, coated Typic Quartzipsamments, characterized as rapidly permeable and strongly acidic sandy soil with nearly level to steep slopes. The Lakeland soil series may be several to as much as 10 m in depth with little to no soil development in the horizons. Generally, the Lakeland series is composed of medium to fine sand and contains 5-10% silt and clay. Commonly associated with Lakeland soils are Chipley, Dorovan, Foxworth, Lucy, and Troup soil series (Overing et al. 1995). Of these, only the Troup Series is present on plots established for this study as delineated by the USDA Soil Surveys of Santa Rosa (Weeks et al. 1980), Walton (Overing and Watts 1989) and Okaloosa Counties (Overing et al. 1995). The Troup series is a loamy, siliceous, thermion Grossarenic, characterized as a moderately permeable soil with nearly level to steep slopes (Overing et al. 1995). The Troup series is dissimilar to the Lakeland series by having a higher silt and clay content between 1.25 and 2 m depth, and has relatively higher densities of very fine and very coarse sand particles. These differences suggest a slightly higher nutrient and soil moisture holding capacity in the Troup series. In general, Troup series occurrences are widely dispersed and small in area at EAFB.

METHODS

Experimental Design

Restoration Blocks. A total of 24, 81-ha (200-acre) plots were established in six blocks of four fire-suppressed hardwood-longleaf pine sandhill plots across an west/east transect of EAFB (Fig. 3.1: B-7, Wolf Creek, Metts Creek, Malone Creek, Exline Creek, C-72). Within each of the six blocks created, site characteristics were considered sufficiently homogeneous among the member plots for our study to conform to a split-plot, randomized complete block design (Steel and Torrie 1980). In keeping with this design, each plot within an experimental block was randomly assigned without replacement to either control designation (no treatment), or to one of three following restoration treatments applied during the spring and early summer of 1995: growing season burn in May and June, herbicide (ULW[®], the granular form of hexazinone with 75% active ingredient applied at a rate of 2.44 kg/ha [2 lb./acre]), and oaks and sand pine felling/girdling by chainsaw (slash not removed). All plots were selected if they were located in areas larger than 81 ha (200 acres) that contained a high density of relatively large diameter hardwood trees, had been fire-suppressed for several decades, and were adjacent to three other such sites. Plots had a relatively sparse herbaceous understory and a thick litter of hardwood leaves interspersed with bare ground. The occurrence of recent small wildfires (<0.5 ha [1 acre]) or small creeks within a plot did not disqualify it from consideration.

In each 81-ha (200-acre) plot, all subplots and sampling stations were located in the 20-ha (50-acre) corner farthest from the neighboring plots of the block to alleviate the potential for recording organisms (i.e., birds, insects) that can travel across adjacent plot boundaries (Fig. 3.2). We borrowed from split-plot terminology to label our nested sampling units: each plot contained 32, 10 × 40-m subplots (Figs. 3.2 and 3.3); any sampling unit within a subplot was referred to as a sub-subplot. The 32 subplots within each plot were arranged in groups of four to test the effect of distance between subplots on the mean and variability of potentially patchy variables, such as species or characteristics that might be clumped in distribution at one or both scales (the split-plot component of the experimental design) (Fig. 3.3). The two distance treatments were 10 and 50 m between centers of two consecutive subplots (effect not tested here). Variables describing soils, herbaceous plants, trees, invertebrates, birds, and mammal activity were quantified on restoration plots. (See below for description of plant variables only.)

Reference Blocks. A total of six 81-ha (200-acre) frequently-burned longleaf pine dominated sandhill plots were established (Fig. 3.1: A-77, A-78, and B-75) to provide objective goals for the restoration of fire-suppressed plots. Reference plots were not part of the restoration experimental design described above, but are a critical research component, because they provide a benchmark for measurement of the success and efficacy of the restoration treatments applied.

Reference plots were chosen on the basis of the following criteria: a square area larger than 81 ha (200 acres), uneven age distribution of longleaf pine, presence of old-growth longleaf pine, abundance of fine fuels interspersed with bare ground, openness of the forest, presence of active red-cockaded woodpecker clusters, and a history of frequent growing season fires. Because of the difficulty in satisfying these requirements, we located only three blocks, each consisting of two 81-ha (200-acre) plots.

Selected reference blocks A-77 and B-75 were designated by the association "*Pinus palustris*/*Quercus laevis*/*Schizachyrium scoparium*-*Rhynchosia cytisoides* Woodland" (The Nature Conservancy 1997a), for which EAFB is the type class. However, reference block A-78 conformed to the type "*Pinus palustris*/*Quercus laevis*/*Aristida beyrichiana*-*Croton argyranthemus* Woodland" (The Nature Conservancy 1997a, Rodgers and Provencher, *in press*). Peet and Allard (1993) also designated these sites as "Southern Xeric Longleaf Pine

Woodlands." The characteristic plants of this group include longleaf pine, turkey oak (*Quercus laevis*), bluejack oak (*Q. incana*), pineywoods dropseed, and gopher apple (*Licania michauxii*). Other common species are wiregrass, persimmon (*Diospyros virginiana*), saw palmetto (*Serenoa repens*), tread softly (*Cnidoscolus stimulosus*), wild buckwheat (*Eriogonum tomentosum*), grass-leaf golden aster, weak-leaf yucca (*Yucca flaccida*), and silver croton (*Croton argyranthemus*) (Peet and Allard 1993).

Each reference plot contained the same subplot sampling design as the experimental plots, but the 20-ha (50-acres) sampling site was located in the plot centers (Fig. 3.3). This arrangement reflected our desire to avoid potential edge effects on these sites. Variables describing soils, herbaceous plants, trees, invertebrates, birds, and mammal activity were quantified on reference blocks.

We collected pre-treatment data from May 1994 to May 1995. The timing of data collection varied with the variable examined (see *Data Collection Timeline*, below). Restoration treatments were applied on restoration plots in the spring and early summer of 1995. Burns in the restoration plots commenced in early April 1995 and were completed during mid-June 1995. ULW[®] was applied during the first week of May 1995. Felling/girdling, the most time consuming of the treatments, was initiated in early June and ended by early August 1995. Treatment application on these plots officially marked the end of the pre-treatment phase of the study. The first late summer/fall post-treatment sampling on these sites began immediately thereafter and was complete by October 1995. The first winter post-treatment sampling spanned from December 1995 until March 1996. The first spring post-treatment sampling was initiated in April and completed at the end of June 1996. Fuel reduction burns were carried out in the 12 ULW[®] and felling/girdling plots from 10 March to 25 April 1997. We sampled those plots at least two weeks after they had burned. We are currently completing our third season of post-treatment sampling on these sites.

For the duration of the restoration study, reference plots will be under a "let burn" management policy. Two reference plots (A-77 east and A-78 west, see Fig. 3.1) accidentally burned during winter 1995; A-78 west burned again during March 1996. Two other reference plots (B-75 north and south) were intentionally burned at the end of summer 1995 in an attempt to limit reproduction of broomsedge and dog fennel, which are native ruderals. The remaining two reference plots burned 15 March 1996 (A-78 west: wildfire) and 25 June 1996 (A-77 west: prescribed burn).

Data Collection. We measured density, height, and DBH (diameter-at-breast-height) of trees (>1.4 m high) in each subplot on restoration and reference plots. DBH of individual trees was determined using a DBH tape, and height was visually estimated in 0.5-m height classes. Heights of longleaf pine >10 m were estimated from DBH measurements using DBH/height equations from an independent data set for EAFB (unpub. data). A clinometer was used in cases where visual height estimates were difficult. Tree viability (i.e., alive, dead, or resprout) was recorded for each individual. For resprouts, DBH and height of the dead bole were measured when resprouts were (<1.4 m high). If resprouts extended above 1.4 m, DBH and height were measured for the largest diameter and tallest resprouting stem. DBH of multi-stemmed trees was determined by measuring an average diameter stem and counting the number of stems.

Based on preliminary analyses, we sub-sampled each 10 × 40-m subplot to facilitate collection of tree density, height, and DBH data. Area sampled was determined by evaluation of variance components for dominant species in successively smaller units. Height and DBH of all longleaf pine within each 10 × 40-m subplot were measured. Longleaf pine juvenile (<1.4 m high) densities were counted based on one-half of the 10 × 40-m area. (Hereafter, we use the term juvenile [<1.4 m high] to describe grass-stage seedlings and saplings that settled prior to the fall 1996 bumper crop. Pre-grass stage longleaf pine are referred to as seedlings, especially those originating from the 1996 crop). Turkey oak was sampled within two 5 × 10-

m areas situated at the narrow ends of each 10 × 40-m subplot (Fig. 3.3). All other tree species were sampled in a randomly selected longitudinal half (i.e., 5 × 40-m) of each 10 × 40-m subplot (Fig. 3.3).

We provide two general measures of understory vegetation: cover of grouped variables, and densities of individual plant species. Cover relates more directly to fuel types and fuel loads and, therefore, may be of greater relevance to land managers. The cover approach simplified what would ordinarily be a complex matrix of variables by combining species that provide similar cover information into general groups or "cover classes." Hence, results from an analysis of cover class data can be of great value in writing burn prescriptions. Alternatively, species densities better reflect the diversity, ecological condition, and mechanisms determining cover for a specific site. The plant species density approach also expressed both species richness and the numerical importance of species. Analysis of species densities is reported only for the pre-treatment and second fall post-treatment data. We believe that it would have been premature to analyze the first year fall post-treatment plant species densities because plots had just been treated and species had not experienced a full reproductive cycle.

Cover was estimated in four 0.5 × 2-m sub-subplots (Fig. 3.3) for graminoids, wiregrass and pineywoods dropseed, forbs, lichens, woody species, bare ground, fine litter, woody litter, and cryptobiotic crust (black form). Graminoids were defined as all grasses and sedges except wiregrass and pineywoods dropseed. Percent cover was estimated in seven cover classes: 0 = 0%; 1 = 1-5%; 2 = 6-25%; 3 = 26-50%; 4 = 51-75%; 5 = 76-95%; and 6 = 96-100%. The following criteria were used in estimating cover: 1) bare ground counted if > 1 cm² of mineral soil visible; 2) lichen cover included only lichens that grew directly on the ground; 3) woody litter included wood covered with lichen; 4) soil with fine root mat and fine organic matter was counted as fine litter; 5) any woody vegetation (<1 m high) was included in cover estimates; 6) plants included in cover were not necessarily rooted within the sub-subplot; 7) percent leaf area of compound leaves was estimated as 60% of the contoured leaf area. Cover of the vegetation could overlap that of soil and each other (e.g., woody species leaf area over grasses) so total cover in the sub-subplots could exceed 100%. Percent cover of the combined tree midstory and canopy (hereafter referred to as "canopy cover") was measured at both 0.5-m ends of each sub-subplot using a spherical densiometer. We reported cover as a proportion in the results (e.g., 50% cover is reported as 0.5).

Understory vegetation densities were also estimated in all restoration and reference plots. Densities were estimated by counting individual plants or stems in the four 0.5 × 2-m sub-subplots in which cover was also estimated. All plants (<1.4 m high) and rooted >50% within each sub-subplot were counted. Highly abundant species were assigned to density classes: I = 1-5; II = 6-10; III = 11-25; IV = 26-50; V = 51-100; VI = 101-150; and VII = >151 individuals. These species were: Darrow's blueberry (*Vaccinium darrowii*), dwarf huckleberry (*Gaylussacia dumosa*), gopher apple, grass-leaf golden aster, and pineland hoary-pea (*Tephrosia mohrii*). For bunch grasses and forbs, clumps separated by >10 cm were considered distinct plants. For all species, the number of flowering stems or clumps was also recorded. A "walk-through" of the 10 × 40-m plot was conducted for a maximum of 10 minutes to record the identity of all plant species present.

Data Collection Timeline. In the restoration and reference plots, response variables and dates of collection are outlined as follows:

Response variable	Beginning date	Ending date
<i>Tree Density, Height, and DBH</i>	15 January 1995 1 November 1995	1 April 1995 1 April 1996
<i>Understory Vegetation and Percent Covers</i>	8 July 1994 1 April 1995 16 July 1995 1 April 1996 1 August 1996	30 October 1994 15 July 1995 1 November 1995 15 July 1996 1 November 1996

Statistical Analyses

We graphed the pre- and post-treatment average whole-plot medians, 25 and 75% quartiles, and minimum and maximum values of statistically significant variables. (Fifty percent of values are smaller or greater than the median. The 25 and 75% quartiles contain the central 50% of the data values—therefore, data from three of six replicates closest to the median are contained within the 25 and 50% quartiles.) We chose to graph the median and 25 and 75% quartiles because they show the actual distribution of the data; however, the statistical tests described below and reported on the figures are based on means and variances. When a variable was not significantly affected by restoration treatments, we tabulated its mean and standard error per treatment and reference plots.

We tested restoration treatment effects with a randomized complete block analysis of covariance (ANCOVA) (Steel and Torrie 1980) for selected variables in restoration plots. The subplot level (sampling distance) of the split-plot design was not tested. We tested the effect of pre-treatment data on post-treatment data as a covariate within the tests for restoration treatments in ANCOVA for restoration plots. In ANCOVA, pre-treatment data were used to adjust post-treatment averages to account for differences among treatments that existed prior to treatment application. The adjusted averages were the values used in the figures. Adjusting means involved using the estimated regression slope obtained from ANCOVA to calculate the expected dependent variable when all independent variables were set to a common average and regression slope (Steel and Torrie 1980). When pre-treatment data are available and meet the assumptions of ANCOVA, this latter method is more precise and powerful than analysis of variance (ANOVA) (i.e., which does not use pre-treatment data) (Sokal and Rohlf 1981, Streng et al. 1993).

We performed three independent contrasts to compare treatment means. Because it is only possible to perform a maximum number of contrasts that is equal to the degrees of freedom for restoration treatments (3) (Sokal and Rohlf 1981), which is less than the number of possible comparisons, we strategically chose to compare the following treatments: control versus burn, burn versus ULW®, and burn versus felling/girdling. The first contrast compared the control to the burn treatment. We thus tested whether doing nothing or maintaining fire suppression (control) performed as well as burning. Burning is the management default at EAFB because it is the least expensive management tool available to managers and because chronic fires would characterize the maintenance condition of sandhills. Both felling/girdling and ULW® are more expensive management techniques in comparison to burning, and their efficacy should be compared to burning, but not to fire suppression.

We conducted ANCOVAs on cover variables, life forms densities, plant species richness, and tree and plant species densities using a computer randomization test (Edgington 1987). Two reasons justified the extra effort of programming the tests. First, we had too many plant variables (>50) to consider and it became cumbersome and very time-consuming to separately test each variable with commercial software. Thus, we wrote a computer program that processed all variables at the same time. Second, many common plant (and invertebrate taxa) species exhibited low densities such that their frequency distributions approach binary distributions, which parametric statistics cannot handle. The randomization procedure is distribution free, but still depends on homogeneous variances among treatments. Briefly, the purpose of the computer test was to create a random distribution for a chosen statistic (e.g., variance) representing the original data through random permutations among treatments (i.e., the null hypothesis was that the observations can belong to any treatment) and then, to determine if the observed statistic from the original unpermuted data was greater than or equal to the 95% of the random values (i.e., if it is in the 5% tail of the distribution). If the original statistic was in the 5% tail of the distribution, the null hypothesis of no difference among restoration treatments was rejected with a significance probability that was equal to 1-(relative rank of the original statistic in the distribution) (Edgington 1987). The three independent contrasts were performed with the same set of permutations and methods, but we used the "t" statistic with standard errors for two adjusted means calculated from ANCOVA (Steel and Torrie 1980) to compare means. We permuted the original data 10,000 times to create a random distribution for each variable. The effect of pre-treatment data on post-treatment values (covariate effect) was determined directly from the F-ratio calculated with the original data, and thus, not the result of permutations. (A new randomization procedure would be required to test the covariate effect.) The significance probability for the covariate effect was approximately determined from a table. We partitioned sum of squares following the ANCOVA formulas in Steel and Torrie (1980) and Cochran and Cox (1957).

We did not test the significance of the block effect, which refers to the source of variation caused by the spatial difference among blocks, because it is impossible to mathematically test such an effect in block designs for which the treatment is applied, repeated, and controlled (i.e., fixed) manipulation (Cochran and Cox 1957, Steel and Torrie 1980). The block*restoration treatment interaction was the error term (i.e., denominator in the F statistic) needed to test the effect of the restoration treatment.

Most of the reported variables needed transformation, because they displayed non-normal distributions (e.g., the proportion of cover) and heterogeneous variances, which are violations of parametric and distribution-free statistics. $\text{Arcsin}(\sqrt{[X+1/2]})$ was used to transform all cover variables (Sokal and Rohlf 1981). Logarithmic transformations ($\ln[X+1]$) were applied to non-cover variables that showed significant and positive mean-variance relationships (e.g., longleaf pine juveniles). For simplicity and ease of reading, we have termed the tests of restoration treatment in the statistical tables as "restoration".

RESULTS

Canopy and Midstory Structure and Composition

The proportion of canopy cover was significantly affected by restoration treatments in 1995 ($P < 0.0000$; Table 3.1), but not in 1996 ($P < 0.0879$). In 1995, the adjusted proportion of canopy cover was significantly lower in burn (40% reduction) compared to control plots ($P < 0.0020$; Fig. 3.4). Adjusted proportions were not significantly different between burn and ULW[®] plots (50% reduction) ($P < 0.3882$; Fig. 3.4), but adjusted proportions in felling/girdling plots were significantly lower than those from burn plots ($P < 0.0001$; Fig. 3.4). In 1996, the median adjusted proportion of canopy cover increased in ULW[®] plots compared to 1995 (Fig. 3.4). Adjusted canopy cover remained lowest in felling/girdling plots.

Median canopy cover in reference plots in 1995 and 1996 was approximately intermediate between adjusted medians observed for the felling/girdling and burn plots.

The adjusted densities and basal areas of the three most common tree species, longleaf pine, turkey oak, and sand live oak (*Quercus geminata*), are shown in Figs. 3.5-3.6. Unadjusted density and basal area were presented in Table 3.2 and Table 3.3 for other species. Most oaks other than laurel oaks (*Quercus hemisphaerica*) showed treatment responses similar to turkey oak. The density and basal area of the following midstory tree species were not significantly affected by treatments (Tables 3.4 and 3.5): weeping haw (*Crataegus lacrimata*) (basal area only), sand holly (*Ilex ambigua*), yaupon (*I. vomitoria*), black cherry (*Prunus serotina*), sparkleberry (*Vaccinium arboreum*) (density only), sand pine, longleaf pine (basal area only), and laurel oak.

The density of longleaf pine was significantly different among treatments ($P < 0.0147$; Table 3.4) due to a lower adjusted median density in burn plots compared to the control plots ($P < 0.0000$; Fig. 3.5). Unadjusted average longleaf pine densities ranged between 1.6 and 1.9 trees/0.01 ha (64.7 and 76.8 trees/acre) in 1995/1996 (Table 3.2). The basal area of longleaf pine was not significantly affected by treatments ($P < 0.7815$; Table 3.5) and was relatively unchanged from 1994/1995 to 1995/1996. Unadjusted average basal area varied between 3.4 and 4.9 m²/0.01 ha (14.5 and 18.37 ft²/acre) (Table 3.3). The range of density of longleaf pine in restoration plots was comparable to that of reference plots in 1994/1995 and somewhat in 1995/1996 (Fig. 3.5; Table 3.2), but median basal area in reference plots was 1.6 to 2 times larger than in restoration plots (Fig. 3.6; Table 3.3).

Turkey oak density and basal area significantly ($P < 0.0000$ and $P < 0.0000$, respectively; Tables 3.4 and 3.5) and similarly responded to treatments. These results matched closely the pattern observed for canopy cover. Adjusted median density and basal area were significantly lower in burn plots compared to control plots ($P < 0.0000$ for density and $P < 0.0000$ for basal area; Figs. 3.5 and 3.6; Tables 3.4 and 3.5) and significantly lower in felling/girdling than in burn plots ($P < 0.0000$ for density and $P < 0.0000$ for basal area; Figs. 3.5 and 3.6; Tables 3.4 and 3.5). The adjusted density of turkey oak was not significantly different between burn and ULW[®] plots ($P < 0.3663$; Table 3.4). Adjusted basal area was significantly lower in ULW[®] compared to burn plots ($P < 0.0081$; Table 3.5). Up to 20.6-fold and 5.7-fold reductions, respectively, based on unadjusted average density and basal area were observed in felling/girdling plots compared to pre-treatment levels. Only 2.4-fold and 1.7-fold reductions were recorded for unadjusted average density and basal area, respectively, in burn plots. Moreover, the variability in density and basal area was substantially higher for the burn treatment than the ULW[®], felling/girdling, and reference plots.

The effect of restoration treatments on sand live oak were mixed compared to those observed on turkey oak. Many large sand live oaks were girdled and were still alive in that treatment two years later. Restoration treatments significantly decreased sand live oak adjusted densities compared to the control ($P < 0.0001$; Table 3.4; Fig. 3.5) as observed with turkey oak. Just as in the case of turkey oak, adjusted densities were not significantly different between the burn and ULW[®] plots ($P < 0.6344$), although they differed for the two other contrasts (Table 3.4; Fig. 3.5). A 4.2-fold reduction in average density was observed in felling/girdling plots, whereas both burn and ULW[®] treatments approximately achieved between 1.6 and 2.2-fold reductions (Table 3.2; Fig. 3.5). Adjusted (and unadjusted) basal area significantly increased in burn plots while slightly decreasing in ULW[®] and felling/girdling plots ($P < 0.0177$; Table 3.5; Fig. 3.6). It was not clear that adjusted basal areas differed among the control, ULW[®], and felling/girdling treatments. Unadjusted average basal area was never greater than 1.4 m²/0.01 ha (5.2 ft²/acre) both pre- and post-treatment (Table 3.3).

Understory Structure and Composition

Understory Cover Classes. The adjusted median proportion of graminoid cover significantly responded to treatments in 1995 ($P < 0.0000$; Table 3.6) and in 1996 ($P < 0.0493$; Table 3.6). The graminoid cover was significantly less in ULW[®] than other plots in 1995 ($P < 0.0003$; Table 3.6). In 1996, graminoid cover was significantly higher in all treatments compared to control plots ($P < 0.0268$; Table 3.6). Cover among restoration treatments was not significantly different, although the largest values were observed in ULW[®] plots (Fig. 3.7).

In 1995, the proportion of forb cover significantly increased in burn plots compared to controls ($P < 0.0000$; Table 3.6; Fig. 3.7). Cover in ULW[®] and felling/girdling were significantly smaller than the burn plot (both $P < 0.0000$; Table 3.6) and, therefore, probably not significantly different from the control. This marked increase of cover in burn plots did not persist in 1996, but median forb cover increased in ULW[®] plots (and the variability) to burn plot levels compared to 1995 ($P < 0.1512$; Fig. 3.7). In any year, the maximum adjusted proportion of forb cover never exceeded 15% (Fig. 3.7) and unadjusted average cover never exceeded 9% (Table 3.7).

Adjusted woody species cover was significantly lower in all restoration treatments than in control plots in 1995 ($P < 0.0001$; Table 3.6; Fig. 3.7), but relative reductions in cover were mostly evident in ULW[®] plots ($P < 0.0000$; Table 3.6). The following year, adjusted median proportion of woody species cover for ULW[®] stayed at the 8% level established in 1995 ($P < 0.0368$; Table 3.6; Fig. 3.7), but burn and felling/girdling plots experienced increased cover comparable to proportions observed in control plots (13%). In the case of burn plots, the increase resulted in significantly higher cover than in control plots ($P < 0.0003$; Table 3.6). The additional effect of burning was to increase woody species cover variability.

Adjusted median proportion of fine litter cover was significantly lower in burned plots (81%; Fig. 3.8; $P < 0.0000$; Table 3.6), and greater in ULW[®] plots (97%; $P < 0.0000$; Table 3.6), compared to control plots in 1995 ($P < 0.0000$; Table 3.6; Fig. 3.8). The pattern of 1995 persisted in 1996, albeit less strongly ($P < 0.0003$; Table 3.6). Adjusted median fine litter cover was generally lower in reference plots than in restoration plots (Fig. 3.8). Fine litter cover varied most in reference plots between years.

Not surprisingly, the adjusted median proportion of woody litter cover was significantly larger in the felling/girdling plots (12%) than in other treatments ($P < 0.0000$; Table 3.6; Fig. 3.8). Woody litter cover was significantly lower in burn plots than in control plots ($P < 0.0000$; Table 3.6). The main difference between years was that adjusted median woody litter cover was significantly greater in burn ($P < 0.0258$; Table 3.6), and maybe ULW[®] plots, compared to control plots in 1996.

We did not graph cover results for bare ground, wiregrass and pineywoods dropseed, and cryptobiotic crust. Fine litter cover was the mirror image of bare groundcover (thus, restoration effects are equally significant for fine litter and bare ground). Although significant in 1995 ($P < 0.0019$; Table 3.6), but not in 1996 ($P < 0.5895$; Table 3.6), the proportion of wiregrass and pineywoods dropseed cover was low ($P < 0.023$; Table 3.7) and probably not important for fire management. Cryptobiotic crust cover results were low, spotty, and never significant.

Plant Life Form Densities. We grouped all plant species found in the sub-subplots into six life forms: clonal shrubs, non-legume forbs, graminoids, legumes, trees, and woody vines. Of all these life form groups, clonal shrubs were the most abundant in restoration and reference plots (Table 3.8). Only graminoids, trees <1.4 m high, and woody vines showed significant treatment effects in at least one year. Adjusted graminoid densities significantly decreased in all restoration treatments in 1995 ($P < 0.0000$; Table 3.8; Fig. 3.9). Adjusted median graminoid

densities were significantly lower in ULW[®] plots than in burn plots ($P < 0.0000$; Table 3.8). The difference between the burn and felling/girdling plots was not significant ($P < 0.6698$; Table 3.8). In 1996, adjusted median density was significantly higher in burn plots than control plots ($P < 0.0165$; Table 3.8), but median density was not significantly different between felling/girdling and burn plots ($P < 0.0958$; Table 3.8). Median density was significantly lower in ULW[®] than in control plots ($P < 0.0002$). Overall, differences among restoration plots were relatively small compared to differences between restoration and reference plots (Fig. 3.9). Graminoid densities were 3 and 2 times higher in reference plots than in restoration plots in 1995 and 1996, respectively (Table 3.7).

The strongest treatment effect on trees < 1.4 m was a significant decrease in adjusted tree density in ULW[®] compared to burn plots, and thus control plots in both years ($P < 0.0429$ in 1995 and $P < 0.0079$ in 1996; Table 3.8; Fig. 3.9). Although small, adjusted median tree density in burn plots was significantly lower in burn than control plots in 1995 ($P < 0.0087$; Table 3.8; Fig. 3.9). The difference between burn and control plots disappeared in 1996 ($P < 0.4753$).

In 1995, adjusted median woody vines density was significantly greater in control than in burn plots ($P < 0.0001$; Table 3.8; Fig. 3.9) and, therefore, than in felling/girdling plots. Adjusted median density was significantly and slightly greater in ULW[®] plots than in burn plots ($P < 0.0119$; Table 3.8). Differences among treatments were not significant in 1996 ($P < 0.4384$; Table 3.8).

Plant Species Richness. A checklist of all plant taxa encountered from spring 1994 through fall 1996 in the longleaf pine restoration plots is provided in Appendix A. A total of 349 taxa representing 72 families and 187 genera was documented. The largest families are the Gramineae (57 spp.), Compositae (53 spp.), and Leguminosae (43 spp.). Low panic grasses (*Dichanthelium* spp.) represent the largest genus with 15 species encountered. Of the 349 plant taxa, there are 244 species that are more commonly associated with sandhills. Sixty-nine species were documented only in subplots that were in close proximity to creek systems, or in subplots that were associated with old creek beds that have potential underground water flow. Thirty-one species were ruderals or plants that were "weedy" in nature occurring typically in disturbed sites. Only five introduced plant species were detected within our plots. Six rare, threatened, or endangered plants were observed and include: Chapman's threeawn (*Aristida simpliciflora*), hairy wild indigo (*Baptisia calycosa* var. *villosa*), toothed savory (*Calamintha dentata*), persistent sedge (*Carex tenax*), Arkansas oak (*Quercus arkansana*), and pineland hoary-pea. Twenty-seven new species were observed in 1996 that had not been encountered in earlier years (Provencher et al. 1996 and 1997; Rodgers and Provencher, *in press*).

Restoration treatments significantly affected the number of plant species (tree, midstory, and groundcover species)/1600 m² in 1996 only ($P < 0.2924$ in 1995 and $P < 0.0065$ in 1996; Table 3.10), although trends were comparable in both years (Fig. 3.10). Median plant species richness was significantly greater in burn plots than in control plots ($P < 0.0000$; Table 3.10). Because adjusted median plant species richness from ULW[®] and felling/girdling plots were significantly smaller than in burn plots ($P < 0.0020$ and $P < 0.0003$, respectively; Table 3.10), they were probably statistically equal to control plot values (Fig. 3.10). Adjusted median plant species richness varied between 56 and 66 plant species/1600 m² in 1995. Median plant species richness varied minimally in reference plots from 1995 to 1996 and always exceeded restoration treatment values.

Understory Plant Species. Adjusted median longleaf pine juvenile densities were significantly affected by restoration treatments in 1995 ($P < 0.0002$; Table 3.11) and in 1996 ($P < 0.0002$). The strongest decrease (approximately 50%) of juveniles was observed in burn plots compared to control plots ($P < 0.0007$; Table 3.11; Fig. 3.11). Juvenile densities were significantly greater in ULW[®] ($P < 0.0004$; Table 3.11) and felling/girdling plots ($P < 0.0008$; Table 3.11) than in burn plots. Juvenile densities, therefore, were probably not statistically

different among the control, felling/girdling, and ULW[®] plots. Densities and significance values for 1996 were practically identical to those of 1995 (Table 3.11; Fig. 3.11).

Among 213 groundcover species recorded, we tested the 57 most common. It is noteworthy that the densities of some of the most characteristic species in sandhills did not change following treatment application. For example, it was hard to differentiate between the pre- and post-treatment average densities of broomsedge, little bluestem, catbrier (*Smilax auriculata*), (dwarf huckleberry after adjusting for sampling with abundance classes), silver croton, Darrow's blueberry, sand live oak seedlings (<1.4 m high), and so on (Table 3.13). These species account for most of the groundcover biomass and abundance. Of these 57, only seven species (listed below) showed significant ($P < 0.05$) responses to restoration treatments: four graminoids, two forbs, and one clonal shrub (Table 3.12).

Of all plant taxa, the low panic grasses (egg-leaf panic grass [*Dichanthelium ovale*] is dominant in this group) most strongly responded to restoration treatments ($P < 0.0004$; Table 3.12; Fig. 3.12). Adjusted median density in control plots was significantly smaller than in burn plots ($P < 0.0007$), which was significantly greater than in ULW[®] ($P < 0.0000$; Table 3.12) and in felling/girdling plots ($P < 0.0058$; Table 3.12). Compared to adjusted median density in control plot, densities increased two-fold in burn plots and 1.3-fold in felling/girdling plots, but decreased 1.7-fold in ULW[®] plots (Fig. 3.12).

Gray's beakrush (*Rhynchospora grayi*), which was probably the most abundant sandhill sedge, was predominantly and negatively affected by ULW[®] application ($P < 0.0000$; Table 3.12; Fig. 3.12). Adjusted median densities did not significantly differ among control, burn, and felling/girdling plots ($P < 0.1899$ for control versus burn and $P < 0.6145$ for burn versus felling/girdling; Table 3.12).

Adjusted median pineywoods dropseed densities significantly decreased in all plots ($P < 0.0010$; Table 3.12; Fig. 3.12) with strongest reductions in ULW[®] plots. Median density was significantly smaller in burn ($P < 0.0368$; Table 3.12) and, by indirect contrast, in felling/girdling plots than control plots. Adjusted median density in ULW[®] plots was significantly less than in burn plots ($P < 0.0029$; Table 3.12).

Lopsided Indian grass (*Sorghastrum secundum*) was not strongly affected by restoration treatments ($P < 0.0395$; Table 3.12). Adjusted median density was greater in restoration treatments compared to control plots (Fig. 3.12), but none of the contrasts were significant (Table 3.12). We deduced from contrast analysis, however, that median density in ULW[®] plots, and perhaps in felling/girdling plots, were significantly greater than in control plots (Fig. 3.12). In 1996, adjusted median densities varied between 0.039 and 0.061 clumps/m², which was not very abundant. Median density was always smaller in reference plots than in restoration plots.

Adjusted median densities of the forb yellow stargrass (*Hypoxis juncea*) were significantly higher in ULW[®] than other plots ($P < 0.0190$; Table 3.12; Fig. 3.13). Median densities were nearly equal for the control, burn, and felling/girdling plots (0.026 stem/m²). Yellow stargrass densities and, especially, variability were higher in reference than restoration plots.

Wireweed (*Polygonella gracilis*) was one of the more ubiquitous forbs of sandhills. All restoration treatments resulted in lower adjusted medians compared to the control ($P < 0.0022$; Table 3.12), although probably not significantly so for the felling/girdling plots (Fig. 3.13). Burning significantly decreased the adjusted median compared to the control ($P < 0.0017$). Because the adjusted median density was not significantly different between ULW[®] and burn plots ($P < 0.3613$; Table 3.12), we concluded that densities significantly differed between control and ULW[®] plots (Fig. 3.13).

Gopher apple was the only woody groundcover species significantly affected by restoration treatments ($P < 0.0111$; Table 3.12). This species was also one of the most abundant in sandhills. The only apparent effect of treatments was an approximate 50% reduction of

adjusted median density in ULW[®] plots ($P < 0.0001$; Table 3.12; Fig. 3.13). Average unadjusted densities approximately varied between 3.3 stems/m² (felling/girdling) and 5.4 stems/m² (ULW[®]), whereas densities of 6.2 stems/m² were observed in reference plots.

DISCUSSION

Canopy Cover and Trees. Restoration treatments had the intended effect of reducing midstory hardwood densities and basal areas, but, as anticipated, responses varied among treatments (Figs. 3.4-3.6; Table 3.14). (To help the reader with a synthetic view of all significant results, we summarized the many significant treatment effects in Table 3.14). Growing season burns achieved only partial topkill of oaks compared to the more thorough reductions accomplished by ULW[®] and felling/girdling treatments. Rebertus et al. (1989a&b) and Glitzenstein et al. (1995) reported that average mortality caused by growing season fire rarely exceeded 58%. The effect of ULW[®] application on midstory and canopy cover reported here (Fig. 3.4) is comparable to those of other studies, which reported hardwood mortality rates of 72-86% (McLemore 1983) and 83-96% (Neary et al. 1981). These mortality rates were dependent on soils, hardwood composition, and rates of application. However, in a recent study of hexazinone at EAFB, Berish (1996) found only 53% oak mortality caused by ULW[®] and 40% for brushbullet one year after treatment, which is lower than those reported above.

In the second post-treatment year, canopy cover recovered noticeably from ULW[®] application. We observed larger oaks, predominantly sand live oak, surviving herbicide application. This recovery could not be confirmed because tree sampling was not conducted during the 1996/1997 winter. Another unintended effect of treatments was a decrease of longleaf pine density in burn plots that experienced hot fires (Fig. 3.5; Table 3.4; Table 3.14). Since adjusted median longleaf pine basal area did not significantly change after treatment application (Fig. 3.6; Table 3.5), we concluded and observed that smaller trees, which have a small influence on basal area, were killed by hot fire.

We used canopy cover, tree density, and basal area to measure the effectiveness of treatments at reducing hardwood encroachment in sandhills. These variables vary substantially in the amount of time required for estimation. Canopy cover is rapidly estimated, whereas counting trees and measuring their DBH are time consuming tasks. Results suggested that canopy cover and tree densities provided qualitatively comparable initial responses to treatment application, but tree basal area revealed a mixed match because basal area of sand live oak was dominated by the contribution of a few large trees that were girdled, but not topkilled. We suggest that canopy cover measurements estimated from a spherical densiometer should be adequate to monitor the response of hardwoods to future management activities.

The ULW[®] form of herbicide and felling/girdling applications cost approximately eight times more than growing season burning (\$99 vs. \$12/ha). We would, therefore, hope for these ULW[®] and felling/girdling to reduce hardwood encroachment at least eight times more effectively or rapidly than fire. Using turkey oak density as a flagship species for hardwood dominance, only felling/girdling application proved cost effective by achieving at least an 8-fold reduction of the dominant oak (Table 3.2). This success occurred even though many large oaks were not girdled because of their wildlife value or survived girdling. Furthermore, felling/girdling has none of the potential toxic side effects of ULW[®] (E. I. DuPont de Nemours and Company, Wilmington, DE) (Duever 1989, Brooks et al. 1993). On the other hand, the ULW[®] form of herbicide-induced mortality greatly reduces resprouting and delays future oaks encroachment. ULW[®], however, does not control encroachment of longleaf stands by sand pine. We now consider other criteria for judging restoration success.

Plant Species Richness. The effect of restoration treatments on plant species richness was only significant in 1996 and significance value increased with years after treatment application

(Fig. 3.10). Only burning significantly increased species richness (Table 3.14). Disturbance types that are common to an ecosystem, such as fire in longleaf pine forests, should result in increased diversity because of selective pressures to respond to that stimulus (Denslow 1980), whereas less common disturbance should not promote such a positive response (Greenberg 1993). For this reason, fire was expected to induce increases in species richness, by stimulating the seed bed and by improving conditions for colonization.

Several studies have reported increased species richness following fire (Lewis and Harshbarger 1976, Walker and Peet 1983, White et al. 1991, Mehlman 1992, Herring and Judd 1995), but the response time for severely fire-suppressed forests was not clear. We observed increasing species richness with each year since burning (Fig. 3.10). Several growing seasons may be required for establishment of colonizing species, although we suspect that recovering and resprouting hardwoods would eventually shade and inhibit herbaceous growth. Mehlman (1992) found that species richness was high and relatively uniform under several fire regimes of moderate to high frequencies in north Florida longleaf pine communities, while low fire frequencies resulted in distinctly lower richness.

Although burning increased plant species richness, an effect that was only significant in 1996, ULW[®] and felling/girdling resulted in lower plant species in 1995 (Fig. 3.10). These patterns may not be statistically supported, but other trends at the species and life form levels suggest truly negative effects. Wilkins et al. (1993) found significant decreases in species diversity at ULW[®] application rates 1.3 times higher than those used in this experiment (3.4 kg/ha vs. 2.4 kg/ha). We observed considerable overlap of the ULW[®] broadcast rows, producing a striped effect of alternating live and dead vegetation. Therefore, a substantial proportion of the sampling area was subject to application rates probably comparable to those reported by Wilkins et al. (1993). We also noticed that several woody species (other than oaks), some of which are uncommon (e.g., scrub mint [*Conradina canescens*]), may be highly sensitive to ULW[®], while other common species appear to not be sensitive (e.g., blueberries, as in Wilkins et al. 1993). We found that low panic grasses (Fig. 3.12), Gray's beakrush (Fig. 3.12), pineywoods dropseed (Fig. 3.12), gopher apple (Fig. 3.13), and the life-form categories graminoids and trees <1.4 m high (Fig. 3.9) all showed significant negative responses to ULW[®] (Table 3.14). Gopher apple was probably the most common woody shrub of sandhills (Kindell et al. 1997, Rodgers and Provencher, *in press*) and is an important food item for gopher tortoise (*Gopherus polyphemus*). Elimination of less common non-target species sensitive to herbicide is unlikely to be noticed by non-botanists while more abundant species (e.g., broomsedge, little bluestem, and dwarf huckleberry [Tables 3.12 and 3.13]) remain unaffected. In addition, small changes in species richness may mask larger changes in species composition and dominance. Wilkins et al. (1993) and Berish (1996) reported initial decreases in cover followed by large increases of several common sandhill species. These changes were accompanied by an overall shift in community composition towards increased dominance of many native ruderals. However, initial changes in species richness may not reflect long-term changes and should be considered with caution.

Detectability may account for some or all of the decrease in species richness in felling/girdling plots in 1995. The abundance of slash present during the 1995 sampling season (Fig. 3.7) covered large patches of the forest floor, making observations of less frequent or minute species more difficult. By fall 1996, dead leaves had fallen from slash and plants on the ground were more easily observed. Species richness increased from 1995 to 1996 to levels found in control plots (Fig. 3.10; Table 3.14). Increased sunlight at the ground level, potential leaching of nutrients from decaying slash (Johnson et al. 1985), and greater retention of moisture by felled slash (Boyer and Miller 1994) may also have influenced the germination of new or dormant species.

In 1996, adjusted median and maximum plant species richness in burn plots overlapped with those from reference plots. Moreover, all treatments in 1996, except the control plots, showed a consistent increase in the number of plant species compared to 1995 (Fig. 3.10).

The maximum unadjusted average number of plant species per 1600 m² was 82 for restoration plots and 89 for reference plots. Walker and Peet (1983) reported a maximum of 82 plant species for 625 m² in the mesic longleaf pine-wiregrass communities of the Green Swamp. The species richness of the Green Swamp, which encompasses wet, mesic, and dry longleaf pine forests, is one of the highest reported in North America, and we believe that the sandhills of EAFB contain similarly impressive numbers of plant species.

Understory Cover Variables. Consistent with several studies (Walker and Peet 1983, Niering and Dreyer 1989, White et al. 1991, Greenberg 1993), the largest and most significant increase of forb cover was observed in the burn and, to a lesser extent, in the felling/girdling plots in 1995 (Fig. 3.7; Table 3.14). In 1996, forb cover achieved its highest density in ULW[®] and burn plots (Fig. 3.7; Table 3.14). Large increases in forb cover in the burn plots may be predominantly attributed to pineland hoary-pea and bracken fern (*Pteridium aquilinum*). We observed pineland hoary-pea, an abundant clonal legume, to readily resprout after fire (significant restoration effect in 1995), and its lateral and vertical growth permits it to cover more area than most other forbs. The phenology of bracken fern appeared to depend on the timing of forest floor disturbance. During the 1994 sampling season, die-back of bracken fern began in mid-July (just prior to initiating sampling). We observed the same seasonality in control plots during 1995. In the 1995 burn plots, however, bracken fern resprouted and experienced delayed senescence. ULW[®] rapidly topkilled bracken fern soon after application (May and early June), and only minimal resprouting was encountered in the fall, which was also found by Berish (1996) at EAFB. The fire stimulation of forbs and inhibitory effects of herbicide on bracken fern waned in 1996, which resulted in a delayed senescence in ULW[®] plots. This delayed senescence and significant increase of yellow stargrass and wireweed densities (Fig. 3.13) in ULW[®] plots may account for greater forb cover (Table 3.14).

Significant treatment effects on forb cover were not entirely due to the cover of these two species. Although non-legume forb and legume life form densities were each marginally significant in 1995 (Table 3.8), rapid inspection of Table 3.9 revealed that their combined density was equal to 7.6 stems/m² in burn plots, whereas the next highest density of 3.5 stems/m² was observed in control and ULW[®] plots. These differences among treatments vanished in 1996. The message here is that forb and legume density was a good predictor of forb cover and has the added benefit of showing that both legumes and non-legume forbs contributed to treatment responses. Moreover, the brevity of the burn effect suggested that annuals partly account for higher densities.

Niering and Dreyer (1989) reported that fires increased forb cover and frequency (e.g., sweet goldenrod [*Solidago odora*]) relative to estimates in unburned Connecticut grasslands. Walker and Peet (1983) showed that forb composition varied with soil moisture and fire frequency in the Green Swamp of North Carolina. The importance of legumes and composites increased from wet to dry sites, whereas only the importance of composites increased with fire frequency. The biomass of some dicot herbs and shrubs decreased with more frequent fires. White et al. (1991) experimentally determined that fire of any frequency and seasonality increased the abundance and the richness of herbaceous species compared to no fire in a 43-year experiment. Compared to periodic winter and summer fire regimes, annual winter and summer fires had the greatest effects on herbaceous species richness, but annual winter fire resulted in the largest increase in herbaceous abundance.

The moderate response of forb cover and density to felling/girdling may have been caused by a large increase in sunlight to the herb-layer and release of nutrients from felled and dying leaves and branches (Johnson et al. 1985, Boyer and Miller 1994). These causal effects also apply to ULW[®] plots and may have counteracted the initial adverse effect of the herbicide on bracken fern and other herbs (e.g., euphorbs and mints).

Our prediction that woody understory species cover would decrease only in ULW[®] and burn plots had mixed results. Cover of woody species significantly decreased in ULW[®] and,

to a lesser extent in burn and felling/girdling plots in 1995 (Fig. 3.7 and Table 3.14). In 1996, hardwood and saw palmetto resprouting caused woody species cover to increase in burn plots (Fig. 3.7). Wilkins et al. (1993) observed that total woody species cover was decreased by the Pronone[®] form of hexazinone at all rates of application, although several species (e.g., Darrow's blueberry and catbrier) were not affected at moderate levels. Concordantly, we observed Darrow's blueberry and dwarf huckleberry resistance to ULW[®] (Tables 3.12 and 3.13), but conspicuous non-target species such as gopher apple (Fig. 3.13) and persimmon (Tables 3.2 and 3.5) were significantly and negatively affected.

The small effect of fire on understory woody species cover in 1995 was best explained by species' vegetative recovery. Species of oaks that occur in sandhills are well known for their ability to rapidly resprout after fire (Rebertus et al. 1989b). Large reserves of root carbohydrates (Woods et al. 1959) and life form modifications into extensive clonal clumps (e.g., sand live oak) enable many species of oaks to persist even under moderate fire regimes. In a long-term study of prescribed fire (Santee Fire plots), 20 years of annual growing season burns were necessary to eliminate oaks from the understory (Waldrop et al. 1987). However, periodic burning resulted in mortality of only mid-sized oaks and a slight decrease in overall densities, indicating that they have a strong resilience to frequent fire regimes.

Prolific and rapid resprouting immediately following fire has also been observed for several woody shrub and groundcover species common to EAFB sandhills including blueberries, huckleberries (White et al. 1991), and saw palmetto (Abrahamson 1984). We also observed catbrier, gopher apple, and dwarf live oak (*Quercus minima*) responding aggressively after fire. Woody understory species cover, therefore, should remain a significant component of groundcover vegetation following restoration burns and was predicted to increase in 1996, which it did.

It is noteworthy that woody species cover was more prominent than grass or forb cover in both restoration and reference plots (Table 3.7). However, when graminoid cover is combined with wiregrass and pineywoods dropseed cover in reference plots, the woody species cover and graminoid cover are comparable. In the Santee Fire plots study in the Francis Marion National Forest, White et al. (1991) have shown shrub and vine cover to be greater than grass cover in periodic summer burns. Graminoid cover dominated that of shrubs and vines in annual winter burn treatments. No-burn controls predominantly supported shrubs and vines. In the Green Swamp, Walker and Peet (1983) also found that shrubs increased in response to periodic fire relative to annual fires. Because annual burns are not really feasible on EAFB sandhills due to low fuel loads, we suggest that a moderate representation of woody understory species may be normal.

The effects of restoration treatments on fine and woody litter cover were anticipated. Fire incinerates the thick litter formed from oak leaves and pine needles. Subsequent post-fire needle and leaf drop results in a thin layer of finer litter on top of bare mineral soil. ULW[®] should increase the thickness of fine litter, but not necessarily its cover, because bare ground accounted for little of the ground surface in the pre-treatment phase (Table 3.14). These explanations suggest that fine litter cover is a poor measure of fine fuel amount and may not relate well to germination success on deep litter; a measure of fine litter volume would be more appropriate. Felling trees produces a large amount of woody litter. These scenarios were confirmed with the exception that post-fire needle and leaf drop was more abundant than initially expected (Fig. 3.8; Table 3.14). Interestingly, fine and woody litter covers were numerically similar among burned restoration plots and reference plots (Fig. 3.8); note that many reference plots burned in 1995 and 1996. The distinction between restoration and reference plots is the composition of the litter. Fine litter in the restoration plots predominantly consists of oak litter, whereas a higher proportion of pine needles and grass necromass is present in the reference plots. These differences in litter composition can have significant effects on fire intensity and behavior (Platt et al. 1991).

The significant, but weak response of graminoid cover to treatments in 1995 and 1996, especially to fire, was an unexpected result. The absence of even weak treatment effects for broomsedge and little bluestem (Tables 3.12 and 3.13), which dominate graminoid biomass and density, and therefore cover, in most EAFB's sandhills (Rodgers and Provencher, *in press*), directly explain these results. We observed that increased grass biomass from 1995 to 1996 due to fire and ULW® effects (Fig. 3.7) translated into increased inflorescence biomass, which formed vertical structures not appreciably contributing to cover. Several published results suggest that post-fire graminoid cover initially decreases but ultimately exceeds its pre-fire cover. Little bluestem demonstrated short-term reductions after burns in Florida (Kalmbacher and Martin 1995). Similarly, Niering and Dreyer (1989) reported initial decreases of grass cover in little bluestem-dominant grasslands of Connecticut after fire. This decrease was followed by significant increases of biomass in subsequent years with both annual and biennial fire regimes. Our results for graminoids are in contrast to Berish's (1996) findings where he observed a significant 35% decrease of grass cover in ULW® plots at EAFB, and an increase of 52% with brushbullets of the same active ingredient. The difference between results presented here and those of Berish (1996) may be explained by methodology. We directly measured graminoid cover from plots, whereas Berish (1996) summed the covers of graminoid species sampled by line-intercept data. Further, Berish (1996) sampled in May, whereas we presented end-of-season results collected from July to November. The fall period is the peak flowering and vegetative season. For these reasons, we are reluctant to compare our results to those of Berish (1996).

Graminoid density, significantly decreased in ULW® plots for 1995 and remained at that density in 1996 (Fig. 3.9; Table 3.14). Three of the four graminoid taxa that significantly responded to treatments in 1996, which included pineywoods dropseed, decreased in ULW® plots and one of these graminoids (low panic grasses) also increased in burn plots (Fig. 3.12; Table 3.14). Lopsided Indian grass, a less commonly occurring grass, increased in ULW® plots (Fig. 3.12; Table 3.14), but not enough to compensate for the reductions of other graminoids. In the long term, herbicide should shift plant dominance from woody species to graminoid/forb cover (given the establishment of a fire regime) (Walker and Peet 1983, Wilkins et al. 1993), but we have not yet observed this shift.

Longleaf Pine Juveniles (<1.4 m High). The minimal decrease of longleaf pine juveniles in control, ULW®, and in felling/girdling plots (Table 3.14; Fig. 3.11) was expected since ULW® is not toxic to pines (McLemore 1983, Griswold 1984) and felling/girdling does not directly affect juveniles unless felled trees crushed juveniles. We believe, however, that decreased detectability of groundcover vegetation in felling/girdling plots partially caused lower count of juveniles. In addition, a hot wildfire in one felling/girdling 81-ha (200-acre) plot killed many juveniles.

Fire was certainly a major source of juvenile mortality in the burn plots. In fact, in the absence of further burning from 1995 to 1996, juvenile densities were remarkably stable (Fig. 3.11). The percent mortality we observed is consistent with values reported in the literature (Boyer 1985, Grace and Platt 1995). Boyer (1990) reported 53% mortality of saplings (1" diameter) following a single growing season burn in southern Alabama. This was comparable to the 56% mortality for seedlings and saplings (<1.4 m high) in this experiment. Pre-grass stage seedling densities as high as 24000/ha have been reduced to 2600/ha within two years of growing season fire at the Wade Tract in southern Georgia (Grace and Platt 1995). Post-treatment juvenile densities in the burn plots, which were 10 times less than those of reference plots, underscore the importance of using restoration methods which protect longleaf pine juveniles within severely fire-suppressed stands. In this experiment, seedbed preparation in the burn plots preceded the 1996 bumper crop, which could ameliorate the potential loss of some seedlings to fire.

The decrease of juvenile longleaf pine densities in reference plots for 1995 represented a 58% mortality following fire. Additional wildfires in 1996 further reduced juvenile densities

(Fig. 3.11). Overall, juvenile densities in reference plots were comparable to those reported for the Wade Tract, Georgia (Grace and Platt 1995) and the Escambia Experimental Forest, Alabama (Boyer 1977). The EAFB longleaf pine juvenile densities were higher than expected given the higher nutrient levels and water availability in the mesic soils of the Wade Tract.

ISSUES OF MANAGEMENT CONCERN

We noted earlier that felling/girdling accomplished the most cost effective and greatest reduction of the midstory (hardwoods and sand pine) relative to the cheaper alternative of growing season burning. On the basis of preservation of longleaf pine juveniles, increased graminoid and forb (legume and non-legume) cover and density, felling/girdling would be favored over ULW[®]. Brushbullet, the alternative form of ULW[®], does not appear to be a better alternative because it killed fewer oaks in Berish's (1996) study at EAFB and, thus, would not meet the primary short-term management goal of hardwood reduction and would cost more in labor than ULW[®] (Berish 1996). Furthermore, the effect of brushbullet on non-target understory vegetation still needs to be evaluated (see above). Restoration treatments imposed in this study, however, are still in progress and, deciding now on a superior treatment may be premature. Also deciding this without considering the effects on wildlife and especially invertebrates, which most birds and reptiles feed on, also would be premature. Felling/girdling and ULW[®] plots were burned in March and April of 1997 for the purpose of reducing fuel loads. (It is a standard practice of burning two dormant seasons after herbicide application and timber stand improvement by chainsaw.) Felling/girdling followed by burns should result in a highly effective restoration effort because fire should further stimulate plant species richness and herbaceous responses.

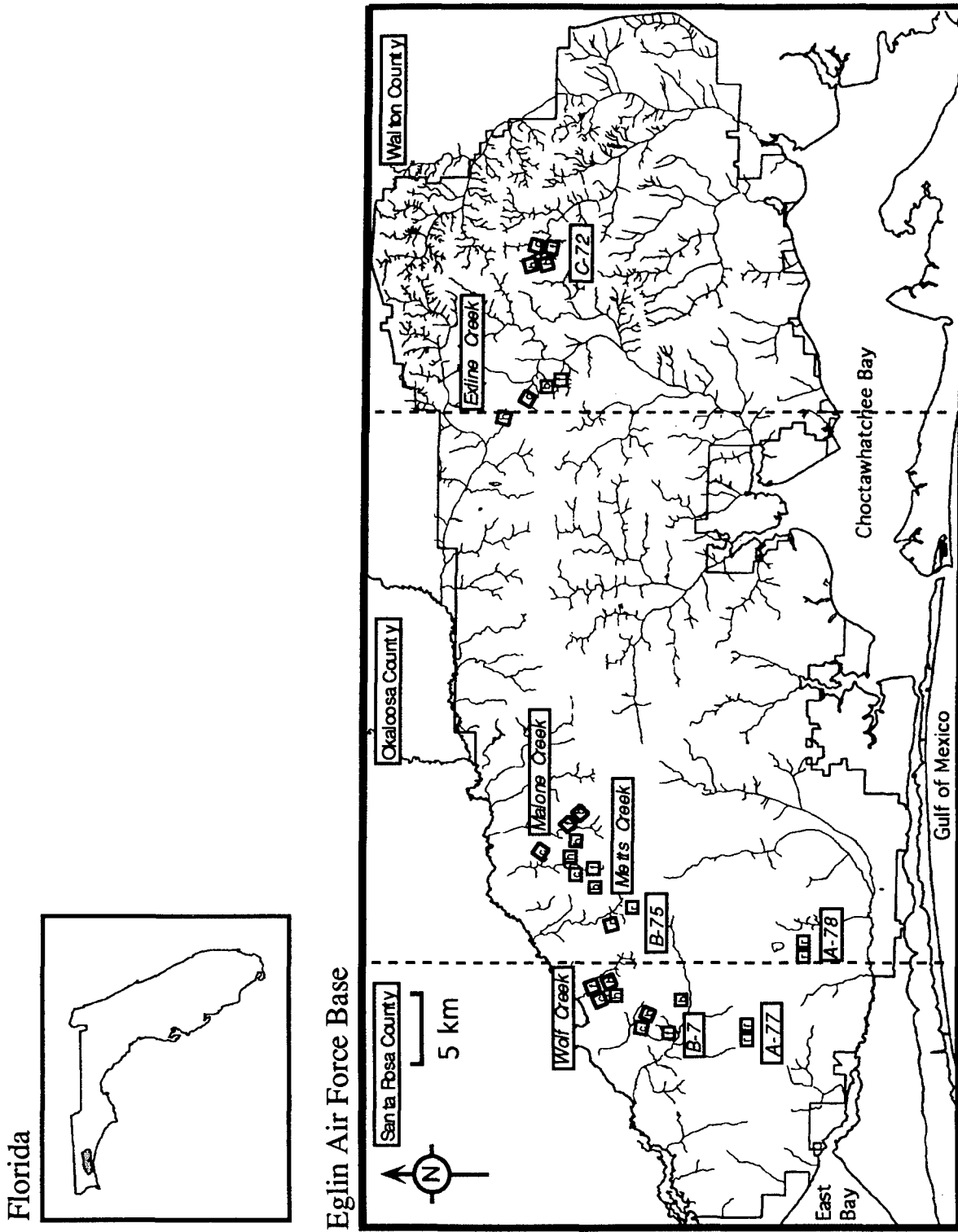


Fig. 3.1. Location of restoration and reference plots on Eglin Air Force Base, Florida. Small squares represent 81-ha (200-acre) plots. Legend: b = burn; c = control; f = felling/girdling; h = herbicide; r = reference.

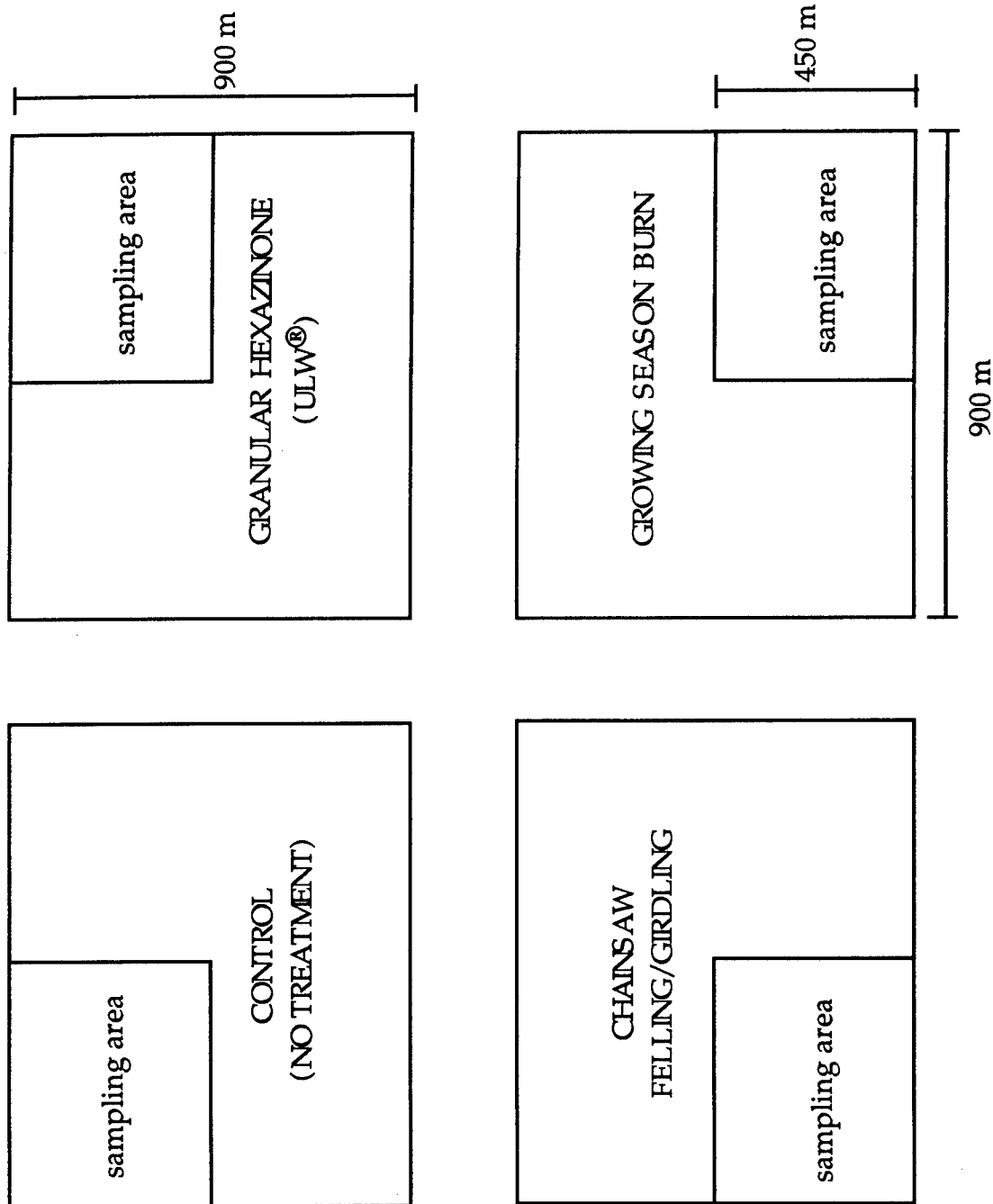


Fig. 3.2. Sample layout of 81-ha (200-acre) restoration plots and sampling areas in one of six blocks in a randomized complete block split-plot design consisting of four whole-plot treatments. See Fig. 3.3 for details of the sampling area.

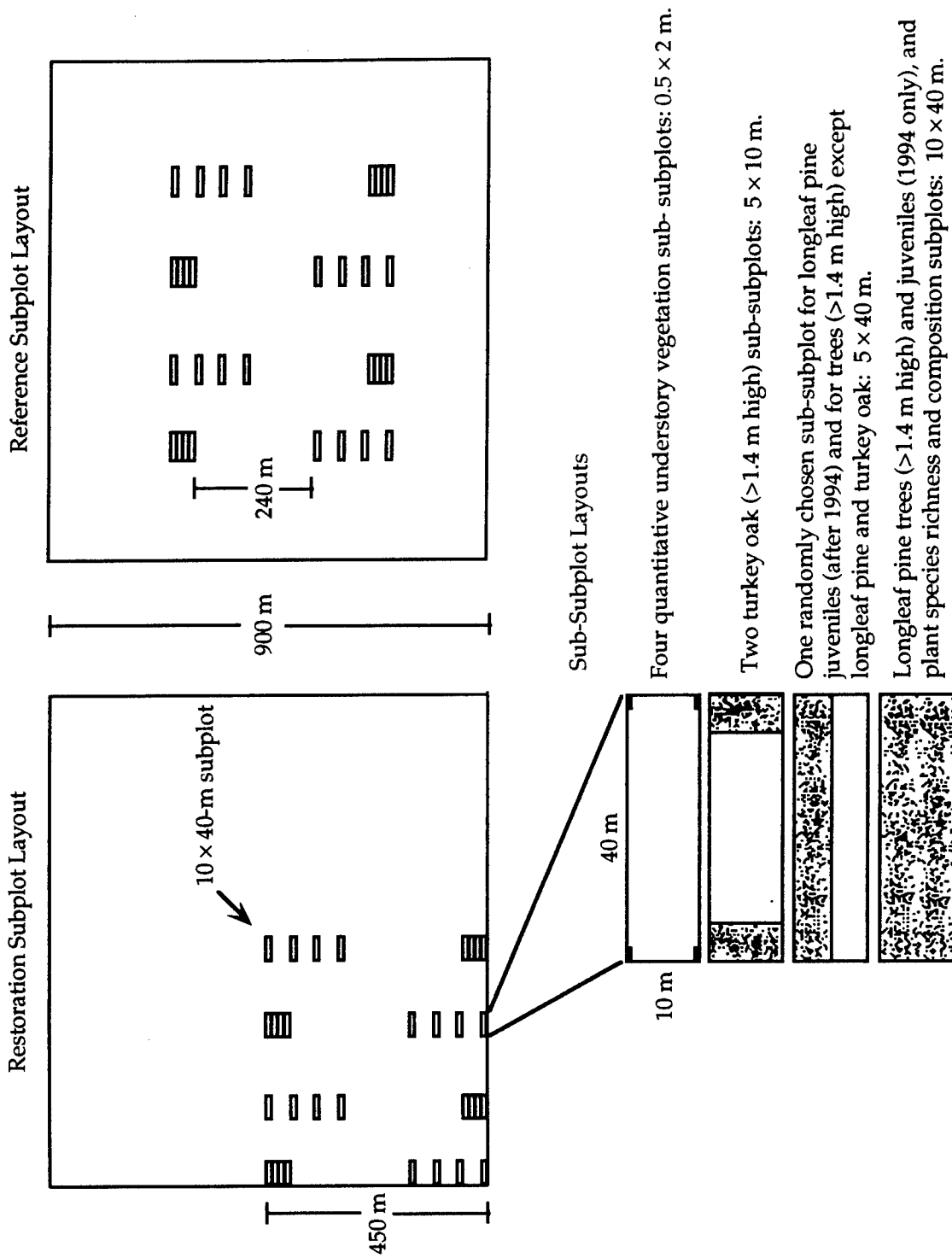


Fig. 3.3. Restoration plot and reference subplot layout. Each plot is composed of 32, 10 × 40-m subplots arranged in four transects. Sampling step is 10 and 50 m. Distance between groups of four subplots per transect is 240 m. Transects are spaced along one plot edge (treatment plots) or centered in the plot (reference plots) and spaced at random distances >100 and <135 m.

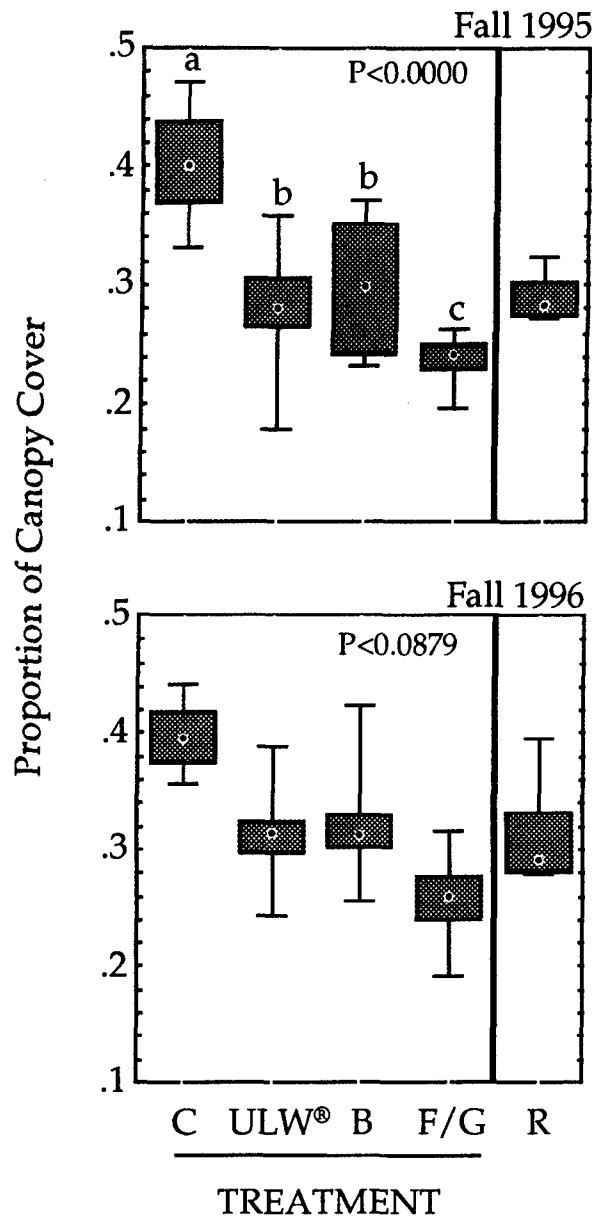


Fig. 3.4. Percent canopy cover (expressed as a proportion) in restoration and reference plots post-treatment (1995 and 1996). Proportions were adjusted for restoration treatments only and were estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW®, and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW® = herbicide.

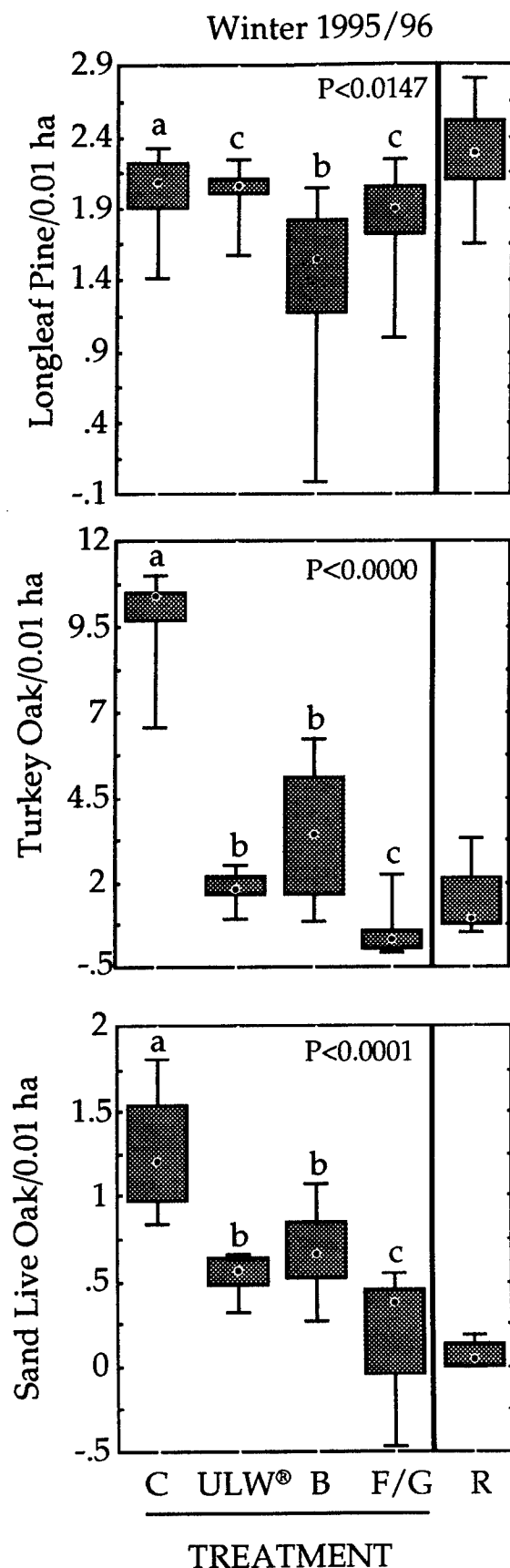


Fig. 3.5. Densities of longleaf pine, turkey oak, and sand live oak in restoration and reference plots post-treatment (1995 and 1996). Densities were adjusted for restoration treatments only and estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW®, and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW® = herbicide.

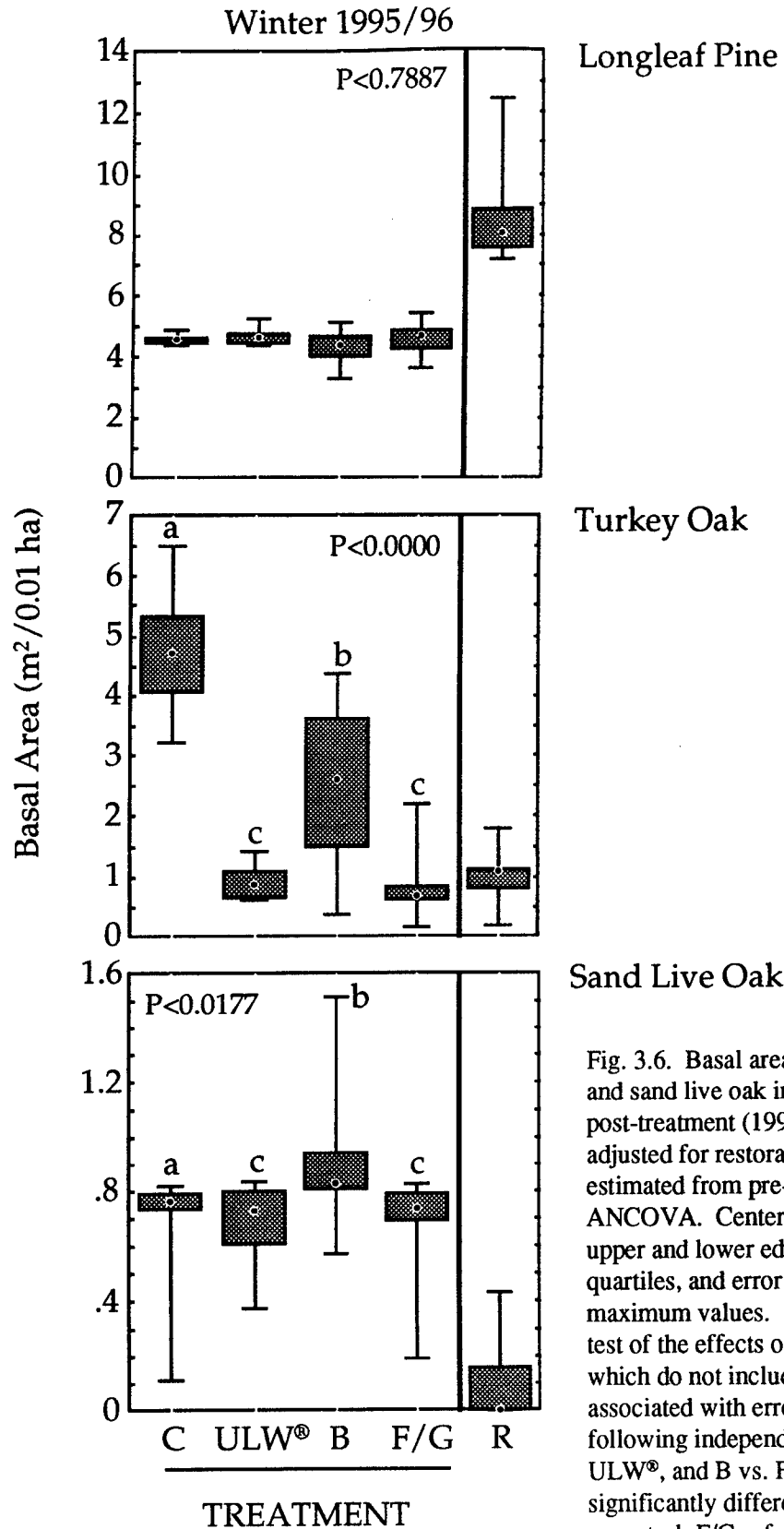


Fig. 3.6. Basal areas of longleaf pine, turkey oak, and sand live oak in restoration and reference plots post-treatment (1995 and 1996). Basal areas were adjusted for restoration treatments only and estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW®, and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW® = herbicide.

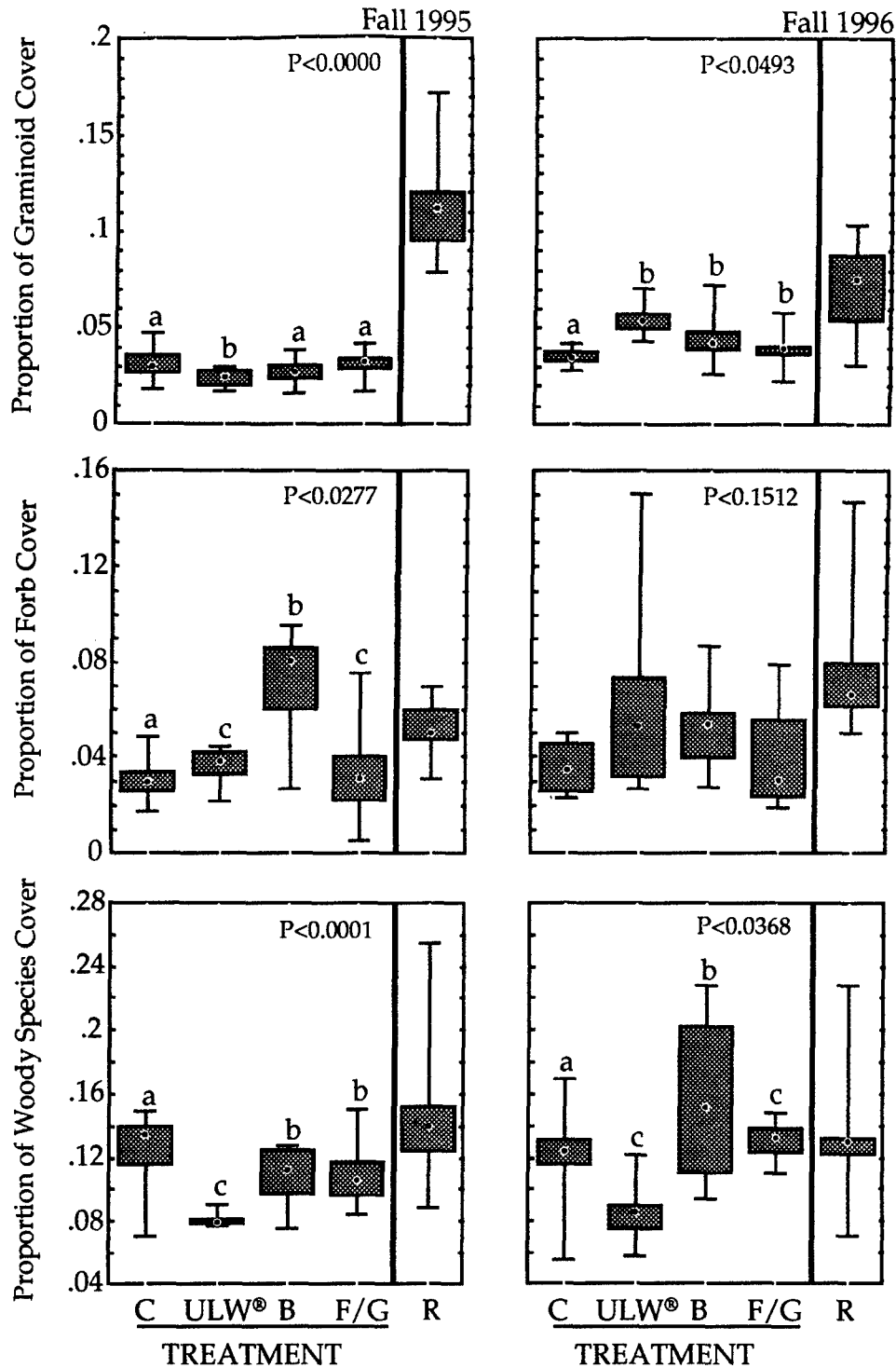


Fig. 3.7. Percent cover (expressed as a proportion) of graminoids, forbs, and woody species in restoration and reference plots post-treatment (1995 and 1996). Proportions were adjusted for restoration treatments only and were estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW®, and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW® = herbicide.

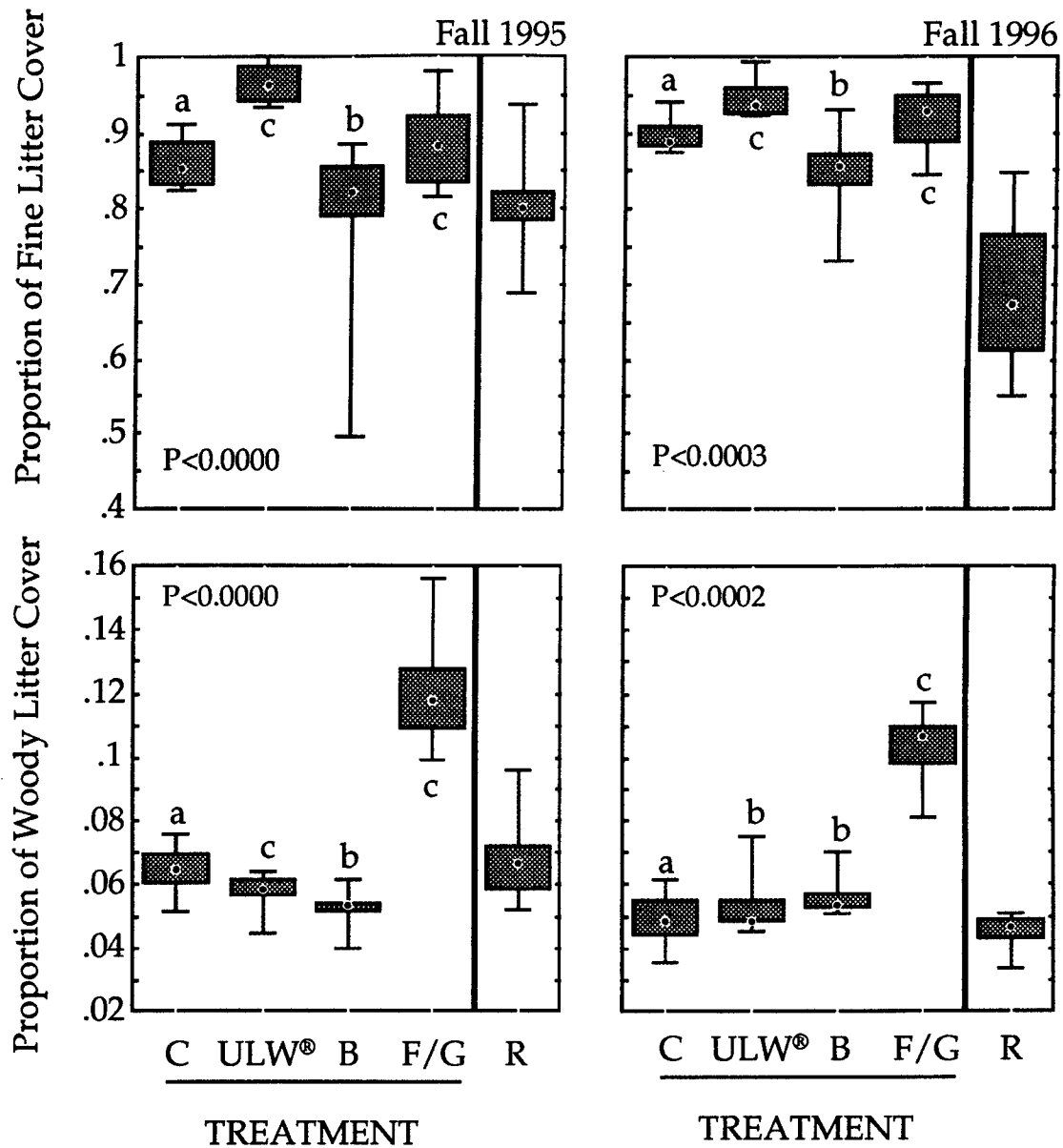


Fig. 3.8. Percent cover (expressed as a proportion) of woody litter and fine litter in restoration and reference plots post-treatment (1995 and 1996). Proportions were adjusted for restoration treatments only and were estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW®, and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW® = herbicide.

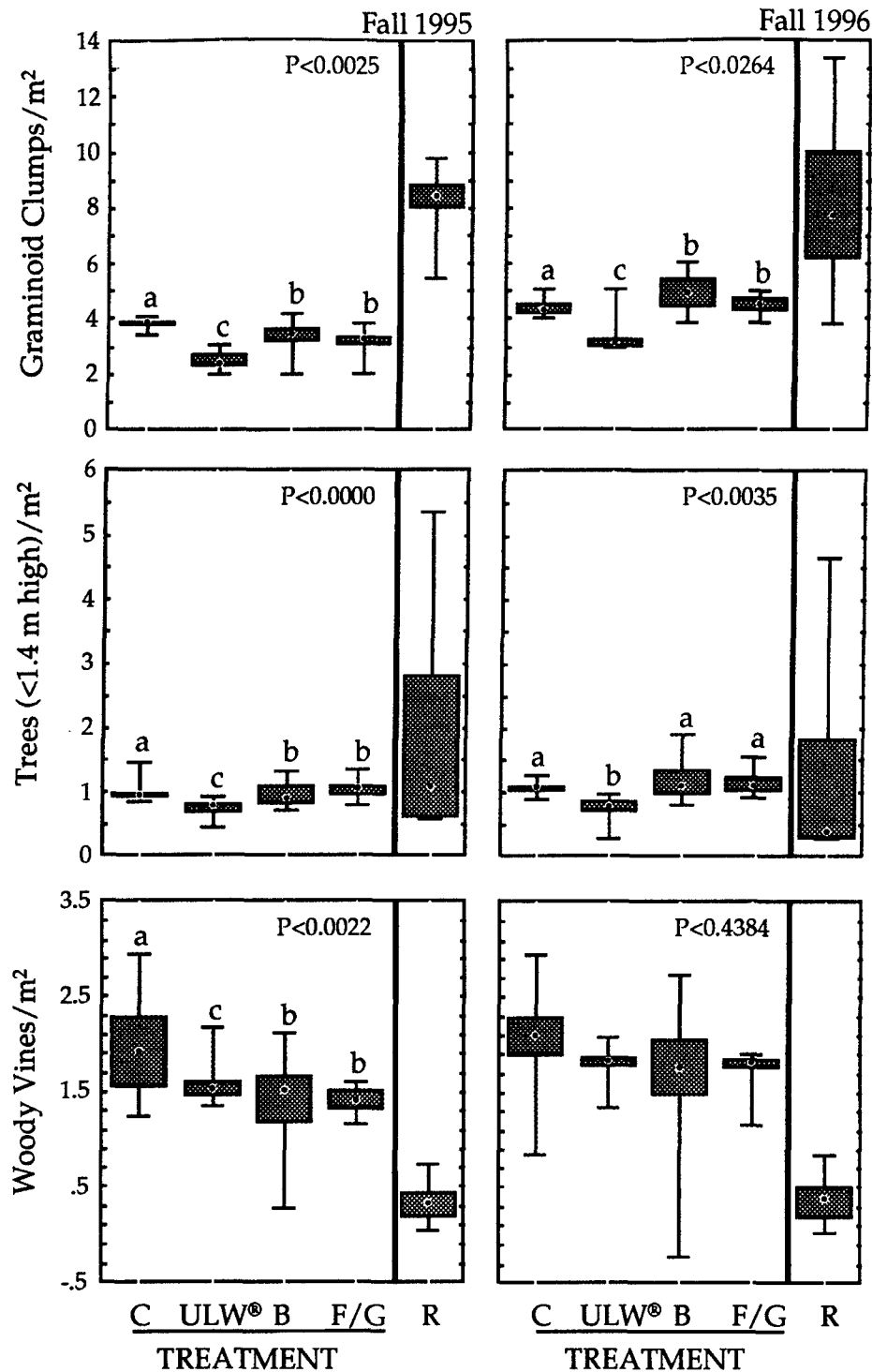


Fig. 3.9. Density of graminoids, trees, and woody vines in restoration and reference plots post-treatment (1995 and 1996). Densities were adjusted for restoration treatments only and were estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW®, and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW® = herbicide.

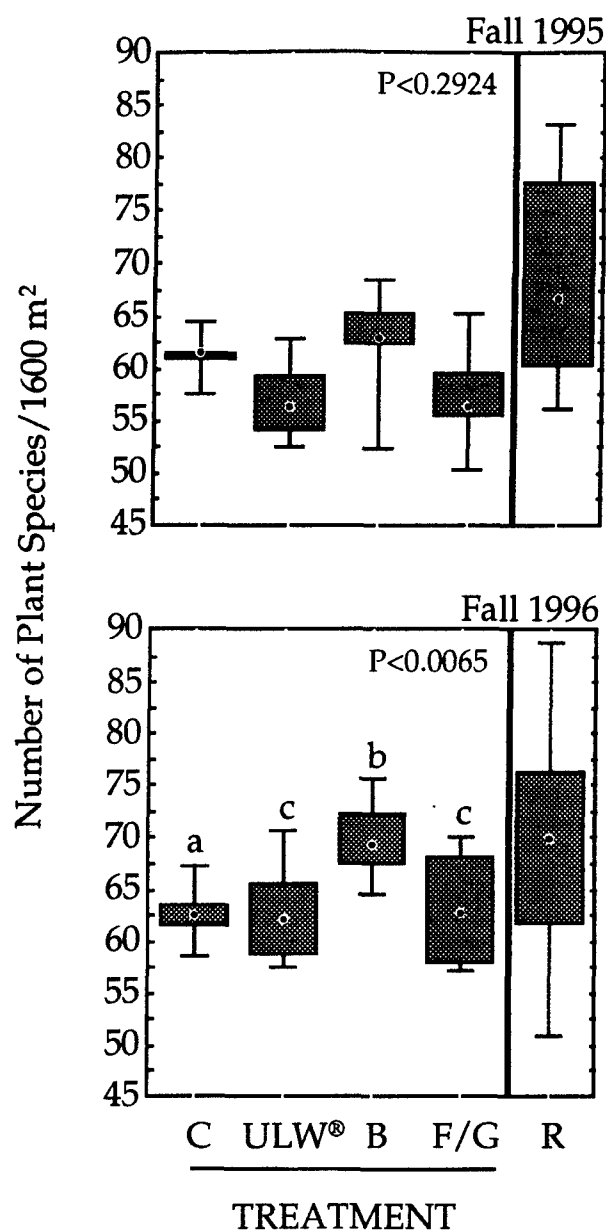


Fig. 3.10. Number of plant species/1600 m² in restoration and reference plots post-treatment (1995 and 1996). Numbers of species were adjusted for restoration treatments only and were estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW®, and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW® = herbicide.

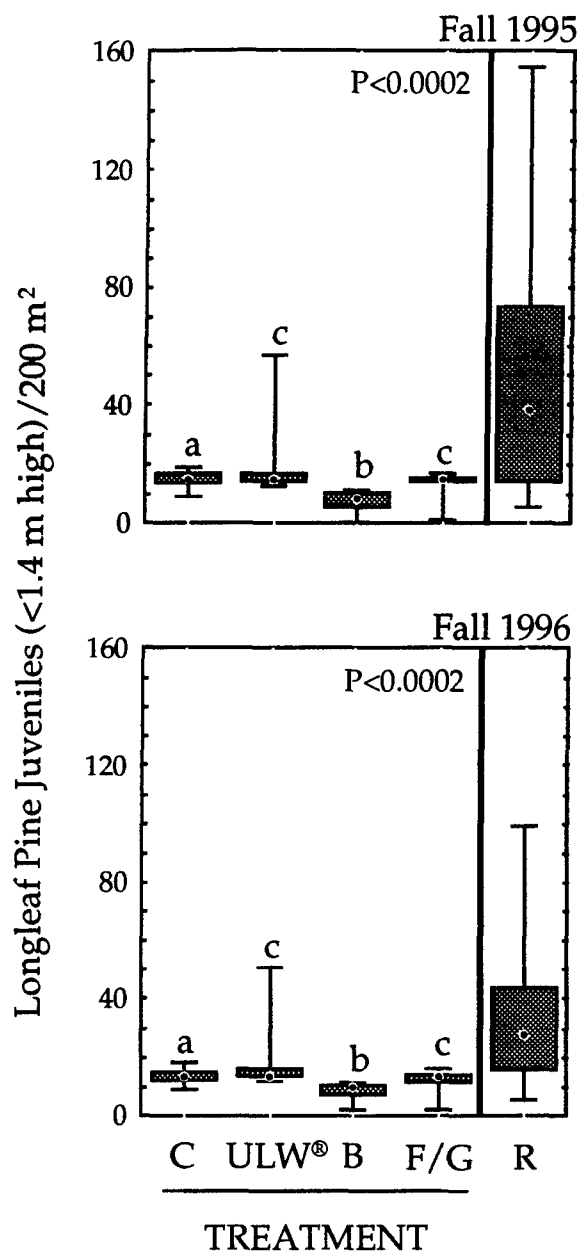


Fig. 3.11. Density of longleaf pine juveniles (<1.4 m high) in restoration and reference plots post-treatment (1995 and 1996). Densities were adjusted for restoration treatments only and were estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW®, and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW® = herbicide.

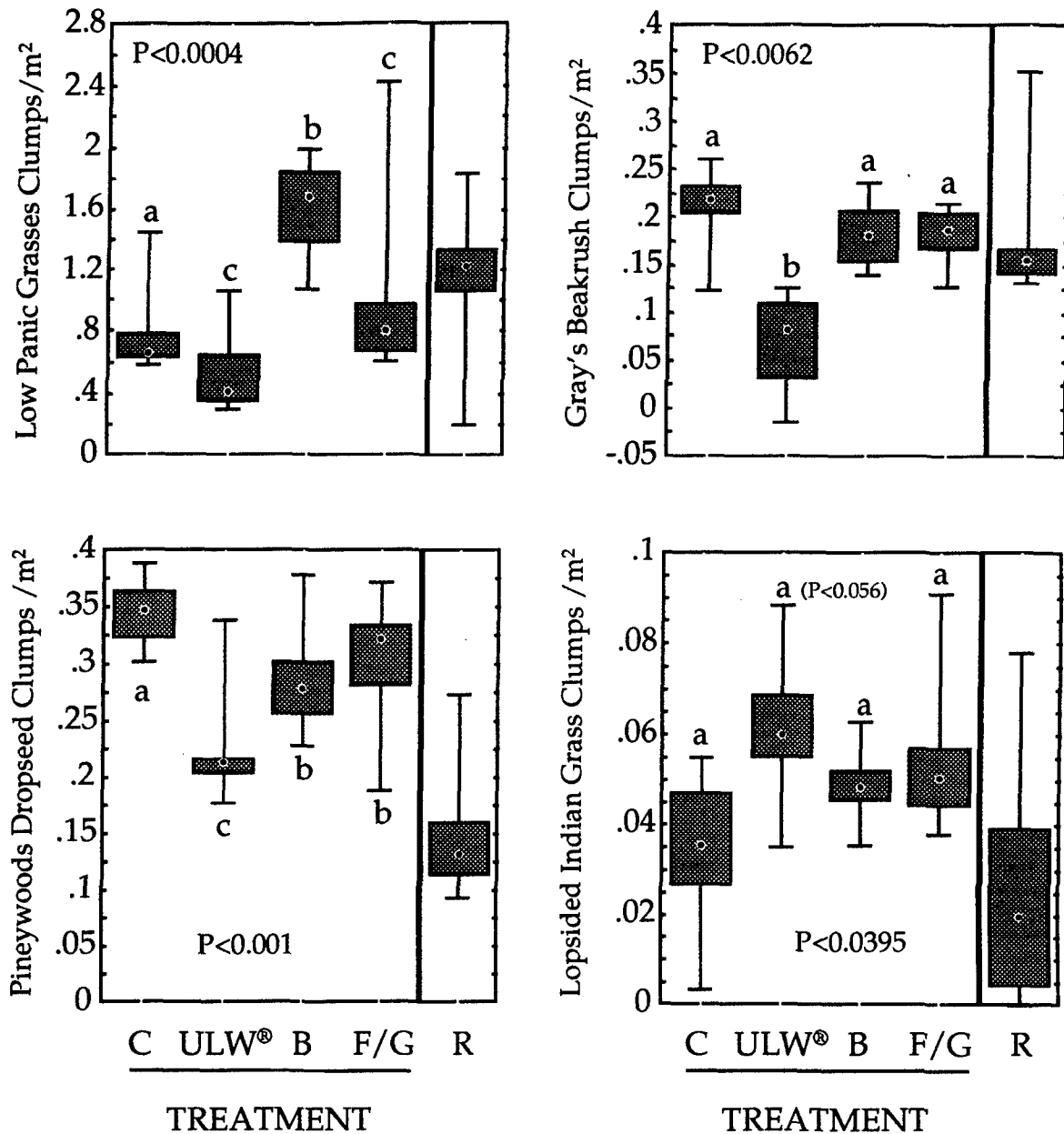


Fig. 3.12. Densities of low panic grasses, Gray's beakrush, pineywoods dropseed, and lopsided Indian grass in restoration and reference plots post-treatment (1995 and 1996). Densities were adjusted for restoration treatments only and estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW[®], and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW[®] = herbicide.

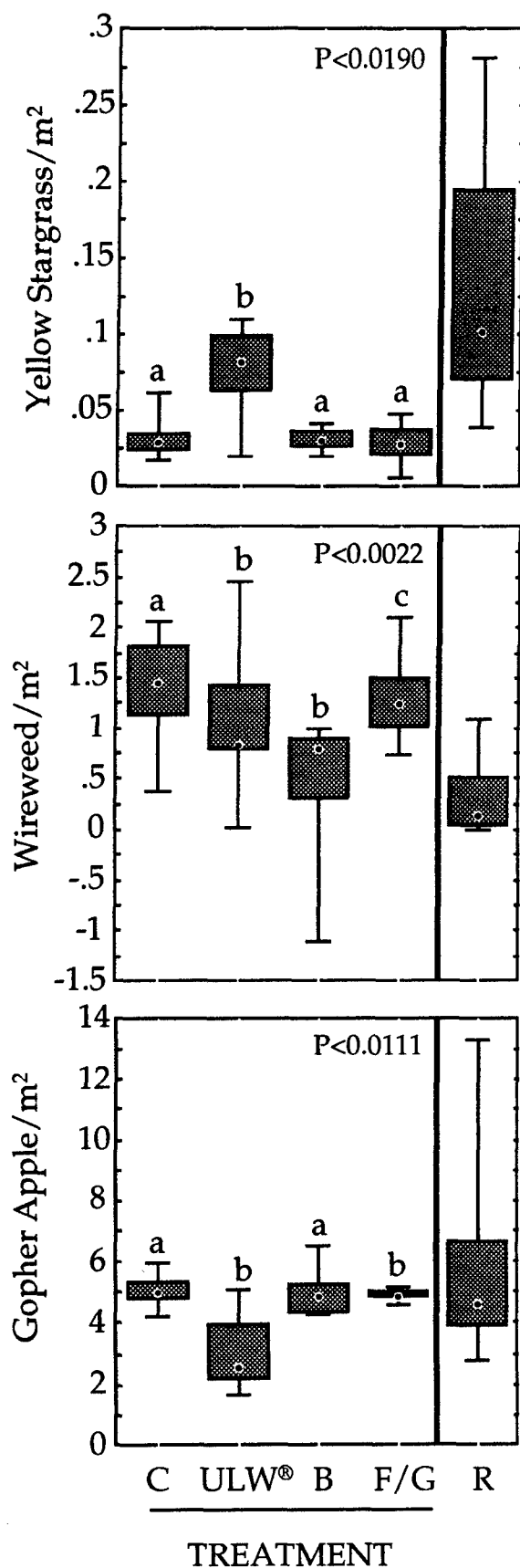


Fig. 3.13. Densities of yellow stargrass, wireweed, and gopher apple in restoration and reference plots post-treatment (1995 and 1996). Densities were adjusted for restoration treatments only and estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW[®], and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW[®] = herbicide.

Table 3.1. Two-way analyses of covariance for tests of restoration treatments and pre-treatment effects on canopy and midstory cover from the fall 1995 and fall 1996 sampling periods in mixed hardwoods and longleaf pine forests at Eglin Air Force Base, Florida. Restoration treatments are growing season burn, application of ULW[®] herbicide, hand felling and girdling of hardwoods and sand pine, and no-treatment control. The experimental design is a complete randomized block, split-plot design, but only the block design at the whole plot level is presented here. The covariate is the fall 1994 pre-treatment data. The error term is the mean square of the interaction of the block and restoration effects. Cover was $\arcsin(\sqrt{X + 0.5})$ transformed to stabilize variances.

Source	Fall 1995				Fall 1996			
	Sum of squares	t-value	d f	p-value	Sum of squares	t-value	d f	p-value
Block	0.2849		5		0.2813		5	
Restoration	0.6359		3	0.0000	0.4334		3	0.0879
Pre-treatment	0.1339		1	0.1000	0.0666		1	0.2000
Error	0.5248		14		0.3146		14	
Contrast								
C vs B†		0.9890	1	0.0020				
B vs F/G		0.6654	1	0.0001				
B vs U		0.2247	1	0.3882				

† Abbreviations of treatments: B = burn; C = control; F/G = felling/girdling; U = ULW[®].

Table 3.2. Mean (± 1 standard error) of tree species densities (stems m^{-2}) per 81-ha (200-acre) restoration treatments and reference plots at Eglin Air Force Base, Florida. Sample size = 6 blocks.

Species	Treatment				Reference
	Control	ULW®	Burn	Felling	
Winter 1994/1995					
<i>Bumelia lanuginosa</i>	0.000 ± 0.000	0.008 ± 0.008	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Castanea pumila</i>	0.042 ± 0.042	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Crataegus lacrimata</i>	0.276 ± 0.238	0.421 ± 0.400	0.417 ± 0.236	0.092 ± 0.058	0.000 ± 0.000
<i>Diospyros virginiana</i>	0.500 ± 0.146	0.643 ± 0.244	0.345 ± 0.078	0.508 ± 0.124	0.690 ± 0.359
<i>Ilex ambigua</i>	0.594 ± 0.256	0.154 ± 0.141	0.070 ± 0.036	0.346 ± 0.229	0.026 ± 0.026
<i>Ilex opaca</i>	0.031 ± 0.019	0.005 ± 0.003	0.010 ± 0.008	0.036 ± 0.036	0.003 ± 0.003
<i>Ilex vomitoria</i>	3.156 ± 1.664	0.628 ± 0.462	1.362 ± 0.963	1.216 ± 0.467	0.057 ± 0.049
<i>Magnolia grandiflora</i>	0.000 ± 0.000	0.008 ± 0.008	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Magnolia virginiana</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.005 ± 0.005	0.000 ± 0.000
<i>Oxydendron arboreum</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.005 ± 0.005	0.000 ± 0.000
<i>Persea borbonia</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Persea palustris</i>	0.000 ± 0.000	0.000 ± 0.000	0.003 ± 0.003	0.000 ± 0.000	0.000 ± 0.000
<i>Pinus clausa</i>	1.695 ± 1.628	0.444 ± 0.357	0.660 ± 0.603	0.831 ± 0.759	0.000 ± 0.000
<i>Pinus elliotii</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.003 ± 0.003	0.000 ± 0.000
<i>Pinus palustris</i>	1.906 ± 0.372	1.775 ± 0.396	2.213 ± 0.391	2.106 ± 0.335	2.332 ± 0.165
<i>Prunus serotina</i>	0.008 ± 0.008	0.023 ± 0.017	0.055 ± 0.046	0.021 ± 0.018	0.000 ± 0.000
<i>Quercus geminata</i>	1.073 ± 0.204	0.820 ± 0.418	1.094 ± 0.454	1.418 ± 0.412	0.167 ± 0.053
<i>Quercus hemisphaerica</i>	0.005 ± 0.005	0.365 ± 0.301	0.398 ± 0.374	0.193 ± 0.177	0.000 ± 0.000
<i>Quercus incana</i>	0.510 ± 0.099	0.424 ± 0.095	0.693 ± 0.172	0.582 ± 0.149	0.081 ± 0.030
<i>Quercus laevis</i>	10.276 ± 0.889	8.557 ± 1.021	7.656 ± 1.605	7.508 ± 1.269	1.844 ± 0.359
<i>Quercus margaretta</i>	0.076 ± 0.064	0.253 ± 0.208	1.073 ± 0.410	0.742 ± 0.136	0.185 ± 0.059
<i>Quercus myrtifolia</i>	0.000 ± 0.000	0.000 ± 0.000	0.003 ± 0.003	0.000 ± 0.000	0.000 ± 0.000
<i>Rhus copallina</i>	0.005 ± 0.005	0.005 ± 0.005	0.008 ± 0.008	0.016 ± 0.016	0.018 ± 0.018
<i>Symplocos tinctoria</i>	0.000 ± 0.000	0.005 ± 0.005	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Vaccinium arboreum</i>	0.440 ± 0.190	0.042 ± 0.021	0.021 ± 0.011	0.182 ± 0.127	0.003 ± 0.003
<i>Vaccinium elliotii</i>	0.000 ± 0.000	0.021 ± 0.018	0.005 ± 0.003	0.000 ± 0.000	0.000 ± 0.000
<i>Vaccinium stamineum</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.012 ± 0.007	0.000 ± 0.000
Winter 1995/1996					
<i>Bumelia lanuginosa</i>	0.010 ± 0.010	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Callicarpa americana</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Castanea pumila</i>	0.016 ± 0.016	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Crataegus lacrimata</i>	0.333 ± 0.315	0.167 ± 0.167	0.250 ± 0.121	0.039 ± 0.025	0.000 ± 0.000
<i>Diospyros virginiana</i>	0.510 ± 0.134	0.247 ± 0.103	0.096 ± 0.048	0.211 ± 0.057	0.432 ± 0.374
<i>Ilex ambigua</i>	0.622 ± 0.282	0.112 ± 0.103	0.010 ± 0.008	0.130 ± 0.113	0.003 ± 0.003
<i>Ilex glabra</i>	0.021 ± 0.021	0.005 ± 0.005	0.000 ± 0.000	0.003 ± 0.003	0.000 ± 0.000
<i>Ilex opaca</i>	0.039 ± 0.030	0.008 ± 0.005	0.000 ± 0.000	0.029 ± 0.029	0.000 ± 0.000
<i>Ilex vomitoria</i>	2.526 ± 1.635	0.529 ± 0.352	0.167 ± 0.145	0.734 ± 0.351	0.047 ± 0.038
<i>Magnolia grandiflora</i>	0.000 ± 0.000	0.013 ± 0.013	0.000 ± 0.000	0.003 ± 0.003	0.000 ± 0.000
<i>Magnolia virginiana</i>	0.000 ± 0.000	0.003 ± 0.003	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Oxydendron arboreum</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.003 ± 0.003	0.000 ± 0.000
<i>Persea borbonia</i>	0.000 ± 0.000	0.003 ± 0.003	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000

Table 3.2. Continued.

Species	Treatment				Reference
	Control	ULW [®]	Burn	Felling	
<i>Pinus clausa</i>	1.750 ± 1.649	0.583 ± 0.466	0.440 ± 0.418	0.026 ± 0.023	0.000 ± 0.000
<i>Pinus palustris</i>	1.885 ± 0.326	1.743 ± 0.390	1.599 ± 0.296	1.930 ± 0.352	2.283 ± 0.179
<i>Prunus serotina</i>	0.010 ± 0.008	0.018 ± 0.015	0.125 ± 0.122	0.013 ± 0.008	0.000 ± 0.000
<i>Quercus geminata</i>	1.260 ± 0.245	0.365 ± 0.205	0.672 ± 0.362	0.336 ± 0.209	0.076 ± 0.038
<i>Quercus hemisphaerica</i>	0.016 ± 0.010	0.109 ± 0.063	0.013 ± 0.013	0.047 ± 0.047	0.000 ± 0.000
<i>Quercus incana</i>	0.438 ± 0.083	0.083 ± 0.028	0.396 ± 0.183	0.016 ± 0.006	0.109 ± 0.041
<i>Quercus laevis</i>	10.068 ± 0.759	1.885 ± 0.254	3.245 ± 1.227	0.365 ± 0.092	1.615 ± 0.522
<i>Quercus margaretta</i>	0.094 ± 0.082	0.049 ± 0.046	0.737 ± 0.279	0.102 ± 0.014	0.089 ± 0.035
<i>Rhus copallina</i>	0.008 ± 0.008	0.008 ± 0.008	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Symplocos tinctoria</i>	0.000 ± 0.000	0.003 ± 0.003	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Vaccinium arboreum</i>	0.531 ± 0.280	0.115 ± 0.091	0.018 ± 0.015	0.031 ± 0.023	0.000 ± 0.000
<i>Vaccinium elliotii</i>	0.063 ± 0.041	0.141 ± 0.081	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Vaccinium stamineum</i>	0.000 ± 0.000	0.003 ± 0.003	0.000 ± 0.000	0.010 ± 0.010	0.000 ± 0.000

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Table 3.3. Mean (± 1 standard error) of tree species basal areas ($\text{m}^2/0.01$ ha) per 81-ha (200-acre) restoration treatments and reference plots at Eglin Air Force Base, Florida. Sample size = 6 blocks.

Species	Treatment				Reference
	Control	ULW [®]	Bum	Felling	
Winter 1994/1995					
<i>Bumelia lanuginosa</i>	0.000 ± 0.000	0.001 ± 0.001	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Castanea pumila</i>	0.004 ± 0.004	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Crataegus lacrimata</i>	0.053 ± 0.038	0.053 ± 0.035	0.110 ± 0.046	0.039 ± 0.027	0.000 ± 0.000
<i>Diospyros virginiana</i>	0.021 ± 0.004	0.033 ± 0.010	0.022 ± 0.006	0.030 ± 0.007	0.007 ± 0.003
<i>Ilex ambigua</i>	0.014 ± 0.007	0.006 ± 0.006	0.003 ± 0.001	0.011 ± 0.006	0.000 ± 0.000
<i>Ilex opaca</i>	0.002 ± 0.002	0.001 ± 0.001	0.000 ± 0.000	0.001 ± 0.001	0.000 ± 0.000
<i>Ilex vomitoria</i>	0.128 ± 0.072	0.023 ± 0.021	0.060 ± 0.046	0.034 ± 0.016	0.000 ± 0.000
<i>Magnolia grandiflora</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Magnolia virginiana</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Oxydendron arboreum</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.013 ± 0.013	0.000 ± 0.000
<i>Persea borbonia</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Persea palustris</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Pinus clausa</i>	0.700 ± 0.690	0.389 ± 0.356	0.188 ± 0.180	0.237 ± 0.228	0.000 ± 0.000
<i>Pinus elliotii</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.002 ± 0.002	0.000 ± 0.000
<i>Pinus palustris</i>	3.350 ± 0.416	5.053 ± 1.104	5.475 ± 1.091	5.096 ± 0.764	9.013 ± 0.879
<i>Prunus serotina</i>	0.000 ± 0.000	0.010 ± 0.006	0.012 ± 0.012	0.002 ± 0.002	0.000 ± 0.000
<i>Quercus geminata</i>	0.682 ± 0.155	0.277 ± 0.112	0.834 ± 0.445	1.428 ± 1.014	0.194 ± 0.092
<i>Quercus hemisphaerica</i>	0.000 ± 0.000	0.105 ± 0.095	0.034 ± 0.033	0.119 ± 0.118	0.000 ± 0.000
<i>Quercus incana</i>	0.290 ± 0.052	0.277 ± 0.058	0.378 ± 0.092	0.259 ± 0.054	0.026 ± 0.015
<i>Quercus laevis</i>	4.958 ± 0.609	5.605 ± 0.981	3.992 ± 0.512	3.714 ± 0.263	1.541 ± 0.516
<i>Quercus margaretta</i>	0.076 ± 0.058	0.237 ± 0.204	0.710 ± 0.224	0.408 ± 0.067	0.201 ± 0.098
<i>Quercus myrtifolia</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Rhus copallina</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Symplocos tinctoria</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Vaccinium arboreum</i>	0.012 ± 0.006	0.002 ± 0.001	0.000 ± 0.000	0.012 ± 0.011	0.000 ± 0.000
<i>Vaccinium elliotii</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Vaccinium stamineum</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
Winter 1995/1996					
<i>Bumelia lanuginosa</i>	0.001 ± 0.001	0.001 ± 0.001	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Callicarpa americana</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Castanea pumila</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Crataegus lacrimata</i>	0.042 ± 0.036	0.012 ± 0.012	0.098 ± 0.047	0.019 ± 0.012	0.000 ± 0.000
<i>Diospyros virginiana</i>	0.029 ± 0.008	0.019 ± 0.007	0.009 ± 0.005	0.011 ± 0.004	0.012 ± 0.009
<i>Ilex ambigua</i>	0.014 ± 0.007	0.008 ± 0.007	0.000 ± 0.000	0.003 ± 0.002	0.000 ± 0.000
<i>Ilex glabra</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Ilex opaca</i>	0.002 ± 0.002	0.001 ± 0.001	0.000 ± 0.000	0.001 ± 0.001	0.000 ± 0.000
<i>Ilex vomitoria</i>	0.082 ± 0.058	0.013 ± 0.010	0.018 ± 0.016	0.034 ± 0.017	0.000 ± 0.000
<i>Magnolia grandiflora</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.005 ± 0.005	0.000 ± 0.000
<i>Magnolia virginiana</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Oxydendron arboreum</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.001 ± 0.001	0.000 ± 0.000
<i>Persea borbonia</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000

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Table 3.3. Continued.

Species	Treatment				Reference
	Control	ULW®	Burn	Felling	
<i>Pinus clausa</i>	0.673 ± 0.661	0.229 ± 0.189	0.159 ± 0.152	0.093 ± 0.085	0.000 ± 0.000
<i>Pinus palustris</i>	3.389 ± 0.416	4.954 ± 1.069	4.934 ± 0.842	4.874 ± 0.794	8.748 ± 0.800
<i>Prunus serotina</i>	0.000 ± 0.000	0.008 ± 0.006	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Quercus geminata</i>	0.537 ± 0.072	0.123 ± 0.046	0.960 ± 0.441	1.311 ± 0.962	0.124 ± 0.080
<i>Quercus hemisphaerica</i>	0.002 ± 0.002	0.018 ± 0.018	0.018 ± 0.018	0.073 ± 0.073	0.000 ± 0.000
<i>Quercus incana</i>	0.237 ± 0.065	0.057 ± 0.012	0.253 ± 0.091	0.034 ± 0.012	0.119 ± 0.107
<i>Quercus laevis</i>	4.824 ± 0.600	1.106 ± 0.194	2.395 ± 0.739	0.727 ± 0.262	0.966 ± 0.228
<i>Quercus margaretta</i>	0.086 ± 0.068	0.070 ± 0.070	0.590 ± 0.214	0.218 ± 0.035	0.113 ± 0.055
<i>Rhus copallina</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Symplocos tinctoria</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Vaccinium arboreum</i>	0.014 ± 0.008	0.001 ± 0.001	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Vaccinium elliotii</i>	0.001 ± 0.000	0.001 ± 0.001	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
<i>Vaccinium stamineum</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000

Table 3.4. Two-way analyses of covariance for tests of restoration treatments and pre-treatment effects on tree species densities from the fall 1996 sampling period in mixed hardwoods and longleaf pine forests at Eglin Air Force Base, Florida. Restoration treatments are growing season burn, application of ULW[®] herbicide, hand felling and girdling of hardwoods and sand pine, and no-treatment control. The experimental design is a complete randomized block, split-plot design, but only the block design at the whole plot level is presented here. The covariate is the fall 1994 pre-treatment data. The error term is the mean square of the interaction of the block and restoration effects. Significance probabilities and sum of squares were calculated by a computer randomization ANCOVA based on 10,000 permutations. Calculations and tests followed Steel and Torrie (1980: 411-419, 215-217, 260). Tree densities were $\log(X+1)$ transformed to stabilize variances.

Source	Sum of squares	t-value	d f	p-value
<i>Crataegus lacrimata</i>				
Block	5.0115		5	
Restoration	0.2060		3	0.0283
Pre-treatment	1.9588		1	0.0025
Error	0.9467		14	
Contrast				
C vs B†		0.4223	1	0.1194
B vs F/G		-0.0322	1	0.2923
B vs U		0.1768	1	0.3318
<i>Diospyros virginiana</i>				
Block	0.6573		5	
Restoration	0.9658		3	0.0001
Pre-treatment	1.0112		1	0.0025
Error	0.7085		14	
Contrast				
C vs B		1.3941	1	0.0000
B vs F/G		-0.2126	1	0.0016
B vs U		-0.2034	1	0.0027
<i>Ilex ambigua</i>				
Block	1.0156		5	
Restoration	0.1791		3	0.2340
Pre-treatment	2.0082		1	0.0025
Error	0.3996		14	
<i>Ilex vomitoria</i>				
Block	13.7196		5	
Restoration	1.5223		3	0.9961
Pre-treatment	9.4555		1	0.0025
Error	4.8120		14	
<i>Pinus clausa</i>				
Block	24.5305		5	
Restoration	2.0242		3	0.0813
Pre-treatment	8.0402		1	0.0025
Error	6.0021		14	
<i>Pinus palustris</i>				
Block	13.2041		5	
Restoration	1.7239		3	0.0147
Pre-treatment	3.3190		1	0.0025

† Abbreviations of treatments: B = burn; C = control; F/G = felling/girdling; U = ULW[®].

Table 3.4. Continued.

Source	Sum of squares	t-value	d f	p-value
Error	3.1328		14	
Contrast				
C vs B		0.9860	1	0.0000
B vs F/G		-0.5871	1	0.0004
B vs U		-0.8883	1	0.0000
<i>Prunus serotina</i>				
Block	0.2328		5	
Restoration	0.0059		3	0.7599
Pre-treatment	0.3972		1	0.0025
Error	0.0908		14	
<i>Quercus geminata</i>				
Block	6.4462		5	
Restoration	5.0570		3	0.0001
Pre-treatment	4.3646		1	0.0025
Error	2.8155		14	
Contrast				
C vs B		0.9303	1	0.0001
B vs F/G		0.8401	1	0.0000
B vs U		0.2367	1	0.6344
<i>Quercus hemisphaerica</i>				
Block	0.2580		5	
Restoration	0.0635		3	0.0743
Pre-treatment	0.1303		1	0.0025
Error	0.1055		14	
<i>Quercus incana</i>				
Block	0.8171		5	
Restoration	2.2712		3	0.0004
Pre-treatment	1.2688		1	0.0025
Error	0.6236		14	
Contrast				
C vs B	1.0417		1	0.0002
B vs F/G	1.3980		1	0.0000
B vs U	0.5962		1	0.1952
<i>Quercus laevis</i>				
Block	10.5947		5	
Restoration	72.4714		3	0.0000
Pre-treatment	1.6724		1	0.5000
Error	15.8046		14	
Contrast				
C vs B		1.7193	1	0.0000
B vs F/G		1.3117	1	0.0000
B vs U		0.4322	1	0.3663
<i>Quercus margaretta</i>				
Block	1.7046		5	
Restoration	1.1803		3	0.0016
Pre-treatment	2.1520		1	0.0025
Error	0.6895		14	

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Table 3.4. Continued.

Source	Sum of squares	t-value	d f	p-value
Contrast				
C vs B		-0.3300	1	0.0771
B vs F/G		1.6268	1	0.0000
B vs U		0.8163	1	0.0090
<i>Vaccinium arboreum</i>				
Block	0.4200		5	
Restoration	0.1201		3	0.2715
Pre-treatment	0.4261		1	0.0025
Error	0.5086		14	

Table 3.5. Two-way analyses of covariance for tests of restoration treatments and pre-treatment effects on tree species basal areas from the fall 1996 sampling period in mixed hardwoods and longleaf pine forests at Eglin Air Force Base, Florida. Restoration treatments are growing season burn, application of ULW[®] herbicide, hand felling and girdling of hardwoods and sand pine, and no-treatment control. The experimental design is a complete randomized block, split-plot design, but only the block design at the whole plot level is presented here. The covariate is the fall 1994 pre-treatment data. The error term is the mean square of the interaction of the block and restoration effects. Significance probabilities and sum of squares were calculated by a computer randomization ANCOVA based on 10,000 permutations. Calculations and tests followed Steel and Torrie (1980: 411-419, 215-217, 260). Tree basal areas were log(X+1) transformed to stabilize variances.

Source	Sum of squares	t-value	df	p-value
<i>Crataegus lacrimata</i>				
Block	0.3935		5	
Restoration	0.0246		3	0.0678
Pre-treatment	0.3670		1	0.0025
Error	0.1376		14	
<i>Diospyros virginiana</i>				
Block	0.0158		5	
Restoration	0.0141		3	0.0143
Pre-treatment	0.0040		1	0.1000
Error	0.0174		14	
Contrast				
C vs B [†]		1.0257	1	0.0000
B vs F/G		0.0425	1	0.4503
B vs U		-0.2790	1	0.0433
<i>Ilex ambigua</i>				
block	0.0033		5	
restoration	0.0027		3	0.3463
pre-treatment	0.0167		1	0.0025
error	0.0053		14	
<i>Ilex vomitoria</i>				
Block	0.2860		5	
Restoration	0.0293		3	0.9999
Pre-treatment	0.3666		1	0.0025
Error	0.3169		14	
<i>Pinus clausa</i>				
Block	68.1774		5	
Restoration	0.6316		3	0.0787
Pre-treatment	45.4442		1	0.0025
Error	3.3369		14	
<i>Pinus palustris</i>				
Block	370.6878		5	
Restoration	3.5572		3	0.7815
Pre-treatment	190.9083		1	0.0025
Error	38.2675		14	
<i>Prunus serotina</i>				
Block	0.0022		5	
Restoration	0.0017		3	0.1889

[†] Abbreviations of treatments: B = burn; C = control; F/G = felling/girdling; U = ULW[®].

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Table 3.5. Continued.

Source	Sum of squares	t-value	df	p-value
Pre-treatment	0.0013		1	0.1000
Error	0.0047		14	
<i>Quercus geminata</i>				
Block	110.5494		5	
Restoration	2.3550		3	0.0177
Pre-treatment	141.4089		1	0.0025
Error	2.6615		14	
Contrast				
C vs B		-0.9976	1	0.0000
B vs F/G		1.0370	1	0.0000
B vs U		1.0040	1	0.0001
<i>Quercus hemisphaerica</i>				
Block	0.6634		5	
Restoration	0.0539		3	0.2763
Pre-treatment	0.3975		1	0.0025
Error	0.2274		14	
<i>Quercus incana</i>				
Block	1.3094		5	
Restoration	1.2197		3	0.0009
Pre-treatment	0.9496		1	0.0025
Error	0.7523		14	
Contrast				
C vs B		0.2500	1	0.2580
B vs F/G		1.1171	1	0.0000
B vs U		1.0270	1	0.0000
<i>Quercus laevis</i>				
Block	125.2278		5	
Restoration	470.0250		3	0.0000
Pre-treatment	7.6502		1	0.5000
Error	106.0713		14	
Contrast				
C vs B		1.4041	1	0.0000
B vs F/G		1.0127	1	0.0000
B vs U		0.9668	1	0.0081
<i>Quercus margaretta</i>				
Block	5.0788		5	
Restoration	1.0504		3	0.0018
Pre-treatment	5.9481		1	0.0025
Error	2.2396		14	
Contrast				
C vs B		-0.3332	1	0.0071
B vs F/G		0.7267	1	0.0012
B vs U		0.8510	1	0.0000
<i>Vaccinium arboreum</i>				
Block	0.0037		5	
Restoration	0.0054		3	0.0189
Pre-treatment	0.0002		1	0.5000
Error	0.0099		14	

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Table 3.5. Continued.

Source	Sum of squares	t-value	df	p-value
Contrast				
C vs B		0.7938	1	0.0000
B vs F/G		0.0811	1	0.9378
B vs U		-0.0379	1	0.0008

Table 3.6. Two-way analyses of covariance for tests of restoration treatments and pre-treatment effects on vegetation cover groups from the fall 1995 and fall 1996 sampling periods in mixed hardwoods and longleaf pine forests at Eglin Air Force Base, Florida. Restoration treatments are growing season burn, application of ULW® herbicide, hand felling and girdling of hardwoods and sand pine, and no-treatment control. The experimental design is a complete randomized block, split-plot design, but only the block design at the whole plot level is presented here. The covariate is the fall 1994 pre-treatment data. The error term is the mean square of the interaction of the block and restoration effects. Cover was $\arcsin(\sqrt{[X + 0.5]})$ transformed to stabilize variances.

Source	Fall 1995				Fall 1996			
	Sum of squares	t-value	df	p-value	Sum of squares	t-value	df	p-value
Wiregrass & pineywoods dropseed								
Block	0.0153		5		0.0303		5	
Restoration	0.0067		3	0.0019	0.0016		3	0.5895
Pre-treatment	0.0922		1	0.0025	0.1797		1	0.0025
Error	0.0124		14		0.0134		14	
Contrast								
C vs B†		0.6868	1	0.0025				
B vs F/G		-0.5212	1	0.0012				
B vs U		0.1739	1	0.4960				
Fine litter								
Block	0.2359		5		0.1533		5	
Restoration	1.6285		3	0.0000	0.4807		3	0.0003
Pre-treatment	0.1566		1	0.2000	0.0537		1	0.2000
Error	0.8211		14		0.2973		14	
Contrast								
C vs B		0.6993	1	0.0000		0.8339	1	0.0007
B vs F/G		-0.9579	1	0.0000		-1.0922	1	0.0000
B vs U		-1.8576	1	0.0000		-1.6512	1	0.0012
Forbs								
Block	0.0846		5		0.2977		5	
Restoration	0.1720		3	0.0277	0.0785		3	0.1512
Pre-treatment	0.0011		1	0.5000	0.0192		1	0.2000
Error	0.1507		14		0.1117		14	
Contrast								
C vs B		-1.3093	1	0.0000				
B vs F/G		1.0264	1	0.0000				
B vs U		1.0341	1	0.0000				
Graminoids‡								
Block	0.0566		5		0.0506		5	
Restoration	0.0263		3	0.0000	0.0159		3	0.0493
Pre-treatment	0.0739		1	0.0025	0.0059		1	0.2000
Error	0.0493		14		0.0481		14	
Contrast								
C vs B		0.1495	1	0.1611		-0.5430	1	0.0268

† Abbreviations of treatments: B= burn; C = control; F/G = felling/girdling; U = ULW®.

‡ Includes all grasses and sedges, except wiregrass and pineywoods dropseed.

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Table 3.6. Continued.

Source	Fall 1995				Fall 1996			
	Sum of squares	t-value	df	p-value	Sum of squares	t-value	df	p-value
B vs F/G	0.0875		1	0.0670	0.3837		1	0.0588
B vs U	0.7459		1	0.0003	-0.1132		1	0.4749
Woody litter								
Block	0.0500		5		0.0202		5	
Restoration	0.3882		3	0.0000	0.2669		3	0.0002
Pre-treatment	0.0432		1	0.0025	0.0093		1	0.0500
Error	0.0433		14		0.0247		14	
Contrast								
C vs B		0.7261	1	0.0000		-0.5867	1	0.0258
B vs F/G		-3.5700	1	0.0000		-3.2748	1	0.0000
B vs U		-0.4277	1	0.0001		0.1170	1	0.7329
Woody species								
Block	0.2959		5		0.7155		5	
Restoration	0.1039		3	0.0001	0.2468		3	0.0368
Pre-treatment	0.1374		1	0.0025	0.1780		1	0.0025
Error	0.1163		14		0.2080		14	
Contrast								
C vs B		0.3916	1	0.0036		-0.7477	1	0.0003
B vs F/G		-0.0918	1	0.4208		0.4689	1	0.0150
B vs U		0.8993	1	0.0000		1.5963	1	0.0000

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Table 3.7. Mean proportion (± 1 standard error) of vegetation cover groups per 81-ha (200-acre) restoration treatments and reference plots at Eglin Air Force Base, Florida. Sample size = 6 blocks.

Cover group	Treatment				Reference
	Control	ULW [®]	Burn	Felling	
Fall 1994					
Graminoids†	0.035 ± 0.003	0.035 ± 0.003	0.030 ± 0.003	0.035 ± 0.005	0.107 ± 0.014
Wiregrass & pineywoods dropseed	0.009 ± 0.001	0.011 ± 0.002	0.006 ± 0.001	0.023 ± 0.009	0.036 ± 0.020
Forbs	0.032 ± 0.008	0.029 ± 0.004	0.029 ± 0.005	0.020 ± 0.002	0.047 ± 0.009
Lichens	0.031 ± 0.009	0.014 ± 0.003	0.023 ± 0.009	0.022 ± 0.004	0.002 ± 0.001
Woody species	0.107 ± 0.011	0.122 ± 0.018	0.098 ± 0.009	0.093 ± 0.007	0.125 ± 0.016
Bare ground	0.033 ± 0.008	0.024 ± 0.004	0.030 ± 0.007	0.026 ± 0.007	0.069 ± 0.016
Fine litter	0.893 ± 0.011	0.930 ± 0.009	0.926 ± 0.010	0.916 ± 0.013	0.805 ± 0.027
Woody litter	0.056 ± 0.009	0.057 ± 0.006	0.049 ± 0.004	0.054 ± 0.004	0.051 ± 0.004
Cryptobiotic crust	0.004 ± 0.001	0.001 ± 0.001	0.004 ± 0.002	0.004 ± 0.001	0.001 ± 0.000
Fall 1995					
Graminoids†	0.033 ± 0.005	0.025 ± 0.003	0.025 ± 0.003	0.032 ± 0.006	0.113 ± 0.014
Wiregrass & pineywoods dropseed	0.008 ± 0.001	0.007 ± 0.002	0.003 ± 0.001	0.018 ± 0.006	0.027 ± 0.014
Forbs	0.029 ± 0.002	0.035 ± 0.003	0.068 ± 0.010	0.039 ± 0.009	0.053 ± 0.006
Lichens	0.025 ± 0.008	0.006 ± 0.002	0.004 ± 0.002	0.010 ± 0.004	0.002 ± 0.001
Woody species	0.124 ± 0.017	0.096 ± 0.016	0.102 ± 0.013	0.100 ± 0.012	0.150 ± 0.023
Bare ground	0.049 ± 0.015	0.011 ± 0.005	0.127 ± 0.010	0.042 ± 0.019	0.073 ± 0.028
Fine litter	0.897 ± 0.019	0.946 ± 0.008	0.766 ± 0.049	0.886 ± 0.020	0.807 ± 0.033
Woody litter	0.067 ± 0.010	0.059 ± 0.004	0.048 ± 0.002	0.121 ± 0.009	0.068 ± 0.007
Cryptobiotic crust	0.003 ± 0.001	0.001 ± 0.000	0.001 ± 0.001	0.002 ± 0.001	0.004 ± 0.002
Fall 1996					
Graminoids†	0.036 ± 0.002	0.055 ± 0.004	0.045 ± 0.007	0.039 ± 0.005	0.070 ± 0.012
Wiregrass & pineywoods dropseed	0.008 ± 0.001	0.007 ± 0.002	0.003 ± 0.001	0.020 ± 0.012	0.017 ± 0.011
Forbs	0.034 ± 0.004	0.064 ± 0.019	0.051 ± 0.008	0.047 ± 0.011	0.080 ± 0.015
Lichens	0.021 ± 0.007	0.009 ± 0.002	0.004 ± 0.002	0.010 ± 0.004	0.000 ± 0.000
Woody species	0.122 ± 0.019	0.104 ± 0.027	0.150 ± 0.031	0.117 ± 0.009	0.134 ± 0.021
Bare ground	0.053 ± 0.009	0.023 ± 0.007	0.126 ± 0.026	0.046 ± 0.016	0.211 ± 0.032
Fine litter	0.919 ± 0.009	0.936 ± 0.007	0.838 ± 0.024	0.915 ± 0.020	0.693 ± 0.049
Woody litter	0.050 ± 0.003	0.055 ± 0.006	0.055 ± 0.004	0.102 ± 0.005	0.045 ± 0.003
Cryptobiotic crust	0.001 ± 0.001	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000

† Includes all grasses and sedges, except wiregrass and pineywoods dropseed.

Table 3.8. Two-way analyses of covariance for tests of restoration treatments and pre-treatment effects on plant life form densities (m^{-2}) from the fall 1995 and fall 1996 sampling periods in mixed hardwoods and longleaf pine forests at Eglin Air Force Base, Florida. Restoration treatments are growing season burn, application of ULW® herbicide, hand felling and girdling of hardwoods and sand pine, and no-treatment control. The covariate is the fall 1994 pre-treatment data. The experimental design is a complete randomized block, split-plot design, but only the block design at the whole plot level is presented here.

Source	Fall 1995				Fall 1996			
	Sum of squares	t-value	df	p-value	Sum of squares	t-value	df	p-value
Clonal shrubs								
Block	80.0648		5		100.0181		5	
Restoration	1.1929		3	0.9892	4.5764		3	0.7321
Pre-treatment	17.1288		1	0.0025	21.8750		1	0.0025
Error	4.8696		14		3.1131		14	
Forbs								
Block	17.433		5		33.0681		5	
Restoration	14.3561		3	0.7734	1.345		3	0.9945
Pre-treatment	9.9575		1	0.0250	8.6742		1	0.0050
Error	17.6237		14		11.7688		14	
Graminoids†								
Block	13.2644		5		9.9557		5	
Restoration	11.5107		3	0	10.2715		3	0.0264
Pre-treatment	23.8279		1	0.0025	24.3559		1	0.0025
Error	9.9818		14		8.1917		14	
Contrast								
C vs B‡		0.4843	1	0.0015		-0.6271	1	0.0165
B vs F/G		0.1146	1	0.6698		0.5446	1	0.0958
B vs U		0.9128	1	0.0000		1.5479	1	0.0002
Legumes								
Block	4.1792		5		6.3745		5	
Restoration	3.3973		3	0.2281	3.0730		3	0.9381
Pre-treatment	8.9063		1	0.0025	6.4738		1	0.0025
Error	1.9797		14		1.9861		14	
Trees								
Block	10.2459		5		11.2426		5	
Restoration	0.1447		3	0.0025	0.2124		3	0.0035
Pre-treatment	3.4965		1	0.0025	4.0423		1	0.0025
Error	0.2368		14		0.3077		14	
Contrast								
C vs B		0.5407	1	0.0087		-0.0243	1	0.4753
B vs F/G		-0.4153	1	0.1147		-0.1178	1	0.4496
B vs U		0.4063	1	0.0429		0.8883	1	0.0079
Woody vines								
Block	9.6477		5		8.6322		5	
Restoration	0.5419		3	0.0022	0.177		3	0.4384
Pre-treatment	8.7588		1	0.0025	12.5268		1	0.0025
Error	0.7863		14		0.4924		14	

† Includes all grasses and sedges, except wiregrass and pineywoods dropseed.

‡ Abbreviations of treatments: B = burn; C = control; F/G = felling/girdling; U = ULW®.

Table 3.8. Continued.

Source	Fall 1995				Fall 1996			
	Sum of squares	t-value	df	p-value	Sum of squares	t-value	df	p-value
Contrast								
C vs B		0.9141	1	0.0001				
B vs F/G		0.0531	1	0.3539				
B vs U		-0.3720	1	0.0119				

Table 3.9. Mean (± 1 standard error) of plant life form densities (stems m^{-2}) per 81-ha (200-acre) restoration treatments and reference plots at Eglin Air Force Base, Florida. Sample size = 6 blocks.

Life form	Treatment				Reference
	Control	ULW [®]	Burn	Felling	
Fall 1994 (pre-treatment)					
Clonal shrubs	19.056 ± 5.209	28.083 ± 9.408	12.678 ± 4.044	13.959 ± 2.921	19.085 ± 4.374
Forbs	1.381 ± 0.322	1.775 ± 0.379	1.182 ± 0.355	1.409 ± 0.523	8.908 ± 4.777
Graminoids†	2.195 ± 0.362	2.659 ± 0.267	1.796 ± 0.193	2.442 ± 0.483	6.428 ± 0.777
Legumes	0.702 ± 0.327	1.405 ± 0.748	2.098 ± 0.971	0.731 ± 0.286	2.479 ± 1.126
Trees	0.648 ± 0.072	0.681 ± 0.287	0.945 ± 0.421	1.771 ± 0.852	2.440 ± 0.703
Woody vines	1.944 ± 0.446	1.469 ± 0.593	3.774 ± 1.327	1.432 ± 0.357	0.351 ± 0.126
Fall 1995					
Clonal shrubs	14.125 ± 2.411	16.321 ± 4.249	9.515 ± 1.668	9.924 ± 1.940	2.207 ± 0.314
Forbs	2.477 ± 0.480	2.498 ± 0.247	4.656 ± 0.922	3.242 ± 0.679	1.903 ± 0.463
Graminoids†	3.912 ± 0.432	2.909 ± 0.461	2.635 ± 0.272	3.397 ± 0.721	2.273 ± 0.175
Legumes	1.089 ± 0.482	0.966 ± 0.331	3.015 ± 1.129	1.076 ± 0.378	0.829 ± 0.271
Trees	0.803 ± 0.191	0.531 ± 0.189	0.894 ± 0.363	1.555 ± 0.695	0.501 ± 0.099
Woody vines	1.839 ± 0.452	1.164 ± 0.440	2.399 ± 0.766	0.937 ± 0.225	0.162 ± 0.046
Fall 1996					
Clonal shrubs	13.513 ± 2.506	14.509 ± 4.178	9.416 ± 2.193	9.868 ± 1.624	2.304 ± 0.372
Forbs	3.526 ± 0.601	4.603 ± 0.826	3.529 ± 0.785	4.620 ± 0.919	2.273 ± 0.573
Graminoids†	4.525 ± 0.529	3.833 ± 0.506	4.214 ± 0.339	4.785 ± 0.736	2.091 ± 0.236
Legumes	1.315 ± 0.554	1.073 ± 0.340	2.737 ± 0.652	1.370 ± 0.443	0.951 ± 0.324
Trees	0.816 ± 0.159	0.496 ± 0.196	1.139 ± 0.506	1.787 ± 0.777	0.331 ± 0.108
Woody vines	1.841 ± 0.535	1.206 ± 0.460	2.977 ± 0.965	1.104 ± 0.231	0.175 ± 0.054

† Includes all grasses and sedges, except wiregrass and pineywoods dropseed.

Table 3.10. Two-way analyses of covariance for tests of restoration treatments and pre-treatment effects on plant species richness from the fall 1995 and fall 1996 sampling periods in mixed hardwoods and longleaf pine forests at Eglin Air Force Base, Florida. Restoration treatments are growing season burn, application of ULW® herbicide, hand felling and girdling of hardwoods and sand pine, and no-treatment control. The covariate is the fall 1994 pre-treatment data. The experimental design is a complete randomized block, split-plot design, but only the block design at the whole plot level is presented here. The error term is the mean square of the interaction of the block and restoration effects. Plant species richness was $\log(X+1)$ transformed to stabilize variances.

Source	Fall 1995				Fall 1996			
	Sum of squares	t-value	d f	p-value	Sum of squares	t-value	d f	p-value
Block	0.8443		5		0.5712		5	
Restoration	0.3022		3	0.2924	0.4415		3	0.0065
Pre-treatment	1.3235		1	0.0025	1.3139		1	0.0025
Error	0.3166		14		0.3462		14	
Contrast								
C vs B†					-1.2855		1	0.0000
B vs F/G					1.0996		1	0.0003
B vs U					1.2401		1	0.0020

† Abbreviations of treatments: B = burn; C = control; F/G = felling/girdling; U = ULW®.

Table 3.11. Two-way analyses of covariance for tests of restoration treatments and pre-treatment effects on the density of longleaf pine juveniles (<1.4 m high, but not from the fall 1996 seed crop) from the fall 1995 and fall 1996 sampling periods in mixed hardwoods and longleaf pine forests at Eglin Air Force Base, Florida. Restoration treatments are growing season burn, application of ULW[®] herbicide, hand felling and girdling of hardwoods and sand pine, and no-treatment control. The covariate is the fall 1994 pre-treatment data. The experimental design is a complete randomized block, split-plot design, but only the block design at the whole plot level is presented here. The error term is the mean square of the interaction of the block and restoration effects. Densities were $\log(X+1)$ transformed to stabilize variances.

Source	Fall 1995				Fall 1996			
	Sum of squares	t-value	d f	p-value	Sum of squares	t-value	d f	p-value
Block	81.9839		5		76.5213		5	
Restoration	42.8652		3	0.0002	31.1775		3	0.0002
Pre-treatment	40.0093		1	0.0025	36.3981		1	0.0025
Error	37.1823		14		30.4475		14	
Contrast								
C vs B†		1.0671	1	0.0007		0.8945	1	0.0022
B vs F/G		-0.7320	1	0.0008		-0.6680	1	0.0020
B vs U		-1.3508	1	0.0004		-1.3114	1	0.0005

† Abbreviations of treatments: B = burn; C = control; F/G = felling/girdling; U = ULW[®].

Table 3.12. Two-way analyses of covariance for tests of restoration treatments and pre-treatment effects on plant species densities from the fall 1996 sampling period in mixed hardwoods and longleaf pine forests at Eglin Air Force Base, Florida. Restoration treatments are growing season burn, application of ULW[®] herbicide, hand felling and girdling of hardwoods and sand pine, and no-treatment control. The experimental design is a complete randomized block, split-plot design, but only the block design at the whole plot level is presented here. The covariate is the fall 1994 pre-treatment data. The error term is the mean square of the interaction of the block and restoration effects. Significance probabilities and sum of squares were calculated by a computer randomization ANCOVA based on 10,000 permutations. Calculations and tests followed Steel and Torrie (1980: 411-419, 215-217, 260). Plant densities were $\log(X+1)$ transformed to stabilize variances.

Source	Sum of squares	t-value	df	p-value
<i>Andropogon gyrans</i>				
Block	1.0378		5	
Restoration	0.0845		3	0.9917
Pre-treatment	0.4020		1	0.0025
Error	0.2386		14	
<i>Andropogon ternarius</i>				
Block	0.0069		5	
Restoration	0.0054		3	0.9812
Pre-treatment	0.0009		1	0.5000
Error	0.0534		14	
<i>Andropogon virginicus</i>				
Block	0.2104		5	
Restoration	0.0365		3	0.7617
Pre-treatment	0.3398		1	0.0025
Error	0.1943		14	
<i>Anthraenantia villosa</i>				
Block	0.0119		5	
Restoration	0.0014		3	0.5121
Pre-treatment	0.0225		1	0.0025
Error	0.0062		14	
<i>Aristida mohrii</i>				
Block	0.1509		5	
Restoration	0.0293		3	0.8128
Pre-treatment	0.4802		1	0.0025
Error	0.0371		14	
<i>Aristida purpurescens</i>				
Block	0.2613		5	
Restoration	0.0331		3	0.9872
Pre-treatment	0.5932		1	0.0025
Error	0.1520		14	
<i>Balduina angustifolia</i>				
Block	0.1694		5	
Restoration	0.0417		3	0.8170
Pre-treatment	0.0117		1	0.5000
Error	0.1459		14	
<i>Chrysopsis gossypina</i>				
Block	0.0423		5	

Table 3.12. Continued.

Source	Sum of squares	t-value	df	p-value
Restoration	0.0010		3	0.4680
Pre-treatment	0.0272		1	0.0025
Error	0.0056		14	
<i>Cnidoscopus stimulosus</i>				
Block	0.2618		5	
Restoration	0.0260		3	0.5154
Pre-treatment	0.1100		1	0.0025
Error	0.0339		14	
<i>Commelina erecta</i>				
Block	0.0100		5	
Restoration	0.0238		3	0.3118
Pre-treatment	0.0037		1	0.2000
Error	0.0296		14	
<i>Crataegus lacrimata</i>				
Block	0.2972		5	
Restoration	0.0038		3	0.2511
Pre-treatment	0.1126		1	0.0025
Error	0.0225		14	
<i>Croton argyranthemus</i>				
Block	0.1856		5	
Restoration	0.0258		3	0.9974
Pre-treatment	0.1932		1	0.0250
Error	0.3500		14	
<i>Danthonia sericea</i>				
Block	0.0110		5	
Restoration	0.0002		3	0.9500
Pre-treatment	0.0157		1	0.0025
Error	0.0111		14	
<i>Dichanthelium</i> spp.				
Block	0.7001		5	
Restoration	4.0986		3	0.0004
Pre-treatment	0.3713		1	0.2000
Error	2.9183		14	
Contrast				
C vs B†		-1.1877	1	0.0007
B vs F/G		0.8252	1	0.0058
B vs U		1.5229	1	0.0000
<i>Eriogonum tomentosum</i>				
Block	0.0547		5	
Restoration	0.0092		3	0.4646
Pre-treatment	0.0603		1	0.0025
Error	0.0093		14	
<i>Eupatorium compositifolium</i>				
Block	0.0269		5	
Restoration	0.0050		3	0.7854
Pre-treatment	0.0140		1	0.0025
Error	0.0160		14	

† Abbreviations of treatments: B = burn; C = control; F/G = felling/girdling; U = ULW®.

Table 3.12. Continued.

Source	Sum of squares	t-value	df	p-value
<i>Euphorbia floridana</i>				
Block	0.0460		5	
Restoration	0.0251		3	0.7259
Pre-treatment	0.0386		1	0.0025
Error	0.0255		14	
<i>Galactia floridana</i>				
Block	0.7416		5	
Restoration	0.4269		3	0.9886
Pre-treatment	0.5095		1	0.0025
Error	0.3103		14	
<i>Gaylussacia dumosa</i>				
Block	56.4951		5	
Restoration	1.1306		3	0.9422
Pre-treatment	13.4401		1	0.0025
Error	1.0056		14	
<i>Hypoxis juncea</i>				
Block	0.0076		5	
Restoration	0.0306		3	0.0190
Pre-treatment	0.0028		1	0.2000
Error	0.0214		14	
Contrast				
C vs B		0.0106	1	0.4914
B vs F/G		0.0894	1	0.5504
B vs U		-1.2643	1	0.0287
<i>Leptoloma cognatum</i>				
Block	0.0047		5	
Restoration	0.0022		3	0.4139
Pre-treatment	0.0054		1	0.0250
Error	0.0092		14	
<i>Liatris spp.</i>				
Block	0.0931		5	
Restoration	0.2019		3	0.4550
Pre-treatment	0.0052		1	0.5000
Error	0.5575		14	
<i>Licania michauxii</i>				
Block	4.1369		5	
Restoration	1.9319		3	0.0111
Pre-treatment	10.3789		1	0.0025
Error	0.6751		14	
Contrast				
C vs B		0.1347	1	0.3702
B vs F/G		-0.3515	1	0.0506
B vs U		2.2567	1	0.0001
<i>Lupinus diffusus</i>				
Block	0.2521		5	
Restoration	0.3205		3	0.2146
Pre-treatment	0.3890		1	0.0025
Error	0.3888		14	

Table 3.12. Continued.

Source	Sum of squares	t-value	d f	p-value
<i>Opuntia humifusa</i>				
Block	0.0009		5	
Restoration	0.0001		3	0.9724
Pre-treatment	0.0014		1	0.0050
Error	0.0021		14	
<i>Panicum virgatum</i>				
Block	0.0342		5	
Restoration	0.0050		3	0.3357
Pre-treatment	0.0751		1	0.0025
Error	0.0121		14	
<i>Paspalum setaceum</i>				
Block	0.0017		5	
Restoration	0.0022		3	0.9551
Pre-treatment	0.0035		1	0.0250
Error	0.0071		14	
<i>Pinus palustris</i>				
Block	1.0731		5	
Restoration	0.0231		3	0.6977
Pre-treatment	0.9377		1	0.0025
Error	0.0672		14	
<i>Pityopsis aspera</i>				
Block	0.0453		5	
Restoration	0.0876		3	0.2611
Pre-treatment	0.3229		1	0.0025
Error	0.0855		14	
<i>Polygonella gracilis</i>				
Block	6.7304		5	
Restoration	2.1354		3	0.0022
Pre-treatment	3.6555		1	0.0025
Error	3.5462		14	
Contrast				
C vs B		0.9159	1	0.0017
B vs F/G		-0.8590	1	0.0000
B vs U		-0.6146	1	0.3613
<i>Pteridium aquilinum</i>				
Block	15.4357		5	
Restoration	2.1993		3	0.9889
Pre-treatment	0.3280		1	0.5000
Error	8.3361		14	
<i>Quercus geminata</i>				
Block	2.3844		5	
Restoration	0.1440		3	0.3421
Pre-treatment	2.6473		1	0.0025
Error	0.1688		14	
<i>Rhynchosia cytisoides</i>				
Block	0.2389		5	
Restoration	0.0579		3	0.9971
Pre-treatment	0.0297		1	0.2000
Error	0.1610		14	

Table 3.12. Continued.

Source	Sum of squares	t-value	df	p-value
<i>Rhynchospora grayi</i>				
Block	0.1592		5	
Restoration	0.2184		3	0.0062
Pre-treatment	0.1765		1	0.0025
Error	0.0983		14	
Contrast				
C vs B		0.2563	1	0.1899
B vs F/G		0.0224	1	0.6145
B vs U		1.5364	1	0.0000
<i>Schizachyrium scoparium</i>				
Block	1.9034		5	
Restoration	0.4582		3	0.4569
Pre-treatment	3.6255		1	0.0025
Error	1.1114		14	
<i>Schizachyrium tenerum</i>				
Block	0.0969		5	
Restoration	0.0126		3	0.7284
Pre-treatment	0.1855		1	0.0025
Error	0.0476		14	
<i>Schrankia microphylla</i>				
Block	0.0428		5	
Restoration	0.0034		3	0.9863
Pre-treatment	0.0080		1	0.0050
Error	0.0120		14	
<i>Scleria ciliata</i>				
Block	0.0301		5	
Restoration	0.0157		3	0.9428
Pre-treatment	0.0134		1	0.1000
Error	0.0434		14	
<i>Serenoa repens</i>				
Block	0.4474		5	
Restoration	0.0017		3	0.7610
Pre-treatment	0.3705		1	0.0025
Error	0.0091		14	
<i>Smilax auriculata</i>				
Block	8.6335		5	
Restoration	0.1775		3	0.4569
Pre-treatment	12.5108		1	0.0025
Error	0.4874		14	
<i>Solidago odora</i>				
Block	0.5028		5	
Restoration	0.2627		3	0.2139
Pre-treatment	0.2508		1	0.0250
Error	0.3978		14	
<i>Sorghastrum secundum</i>				
Block	0.0256		5	
Restoration	0.0060		3	0.0395
Pre-treatment	0.0123		1	0.0025
Error	0.0141		14	

Table 3.12. Continued.

Source	Sum of squares	t-value	df	p-value
Contrast				
C vs B		-0.5149		0.0744
B vs F/G		-0.2038		0.1336
B vs U		-0.3165		0.0559
<i>Sporobolus junceus</i>				
Block	0.3852		5	
Restoration	0.0913		3	0.0010
Pre-treatment	0.9716		1	0.0025
Error	0.0653		14	
Contrast				
C vs B		0.5664	1	0.0368
B vs F/G		-0.1209	1	0.3045
B vs U		0.9386	1	0.0029
<i>Stylisma patens</i>				
Block	0.0350		5	
Restoration	0.1009		3	0.9055
Pre-treatment	0.0783		1	0.0025
Error	0.0700		14	
<i>Stylosanthes biflora</i>				
Block	0.0022		5	
Restoration	0.0001		3	0.9717
Pre-treatment	0.0017		1	0.0025
Error	0.0008		14	
<i>Tephrosia chrysophylla</i>				
Block	0.0386		5	
Restoration	0.0290		3	0.6883
Pre-treatment	0.0042		1	0.5000
Error	0.0479		14	
<i>Tephrosia mohrii</i>				
Block	7.2346		5	
Restoration	0.3112		3	0.0930
Pre-treatment	7.5759		1	0.0025
Error	0.8659		14	
<i>Tradescantia hirsutiflora</i>				
Block	0.0050		5	
Restoration	0.0009		3	0.8774
Pre-treatment	0.0023		1	0.0500
Error	0.0058		14	
<i>Tragia smallii</i>				
Block	0.3817		5	
Restoration	0.0060		3	0.3110
Pre-treatment	0.3276		1	0.0025
Error	0.0199		14	
<i>Tragia urens</i>				
Block	0.3612		5	
Restoration	0.0761		3	0.1400
Pre-treatment	0.0485		1	0.1000
Error	0.2107		14	

Table 3.12. Continued.

Source	Sum of squares	t-value	df	p-value
<i>Triplasis americana</i>				
Block	0.1126		5	
Restoration	0.0071		3	0.2787
Pre-treatment	0.1363		1	0.0025
Error	0.0910		14	
<i>Vaccinium darrowii</i>				
Block	4.8851		5	
Restoration	0.0056		3	0.5177
Pre-treatment	0.7425		1	0.0025
Error	0.0396		14	
<i>Yucca flaccida</i>				
Block	0.0045		5	
Restoration	0.0004		3	0.8135
Pre-treatment	0.0026		1	0.0250
Error	0.0053		14	

Table 3.13. Mean (± 1 standard error) of 57 common groundcover plant species densities (stems m^{-2}) per 81-ha (200-acre) restoration treatments and reference plots at Eglin Air Force Base, Florida. Sample size = 6 blocks.

Species	Treatment				Reference
	Control	ULW [®]	Burn	Felling	
Fall 1994 (pre-treatment)					
<i>Ageratina aromatica</i>	0.000 ± 0.000	0.000 ± 0.001	0.003 ± 0.002	0.007 ± 0.007	0.848 ± 0.787
<i>Andropogon gyrans</i>	0.181 ± 0.085	0.154 ± 0.087	0.090 ± 0.025	0.111 ± 0.027	0.125 ± 0.025
<i>Andropogon ternarius</i>	0.196 ± 0.095	0.087 ± 0.052	0.051 ± 0.013	0.109 ± 0.045	0.161 ± 0.093
<i>Andropogon virginicus</i>	0.326 ± 0.129	0.228 ± 0.142	0.155 ± 0.049	0.120 ± 0.041	3.231 ± 0.681
<i>Anthraenantia villosa</i>	0.018 ± 0.012	0.029 ± 0.011	0.052 ± 0.031	0.012 ± 0.004	0.005 ± 0.004
<i>Aristida beyrichiana</i>	0.000 ± 0.000	0.000 ± 0.008	0.008 ± 0.008	0.392 ± 0.325	0.734 ± 0.517
<i>Aristida mohrii</i>	0.167 ± 0.067	0.156 ± 0.062	0.165 ± 0.060	0.109 ± 0.036	0.112 ± 0.047
<i>Aristida purpurescens</i>	0.236 ± 0.103	0.195 ± 0.096	0.182 ± 0.038	0.169 ± 0.066	0.228 ± 0.093
<i>Balduina angustifolia</i>	0.018 ± 0.014	0.010 ± 0.004	0.009 ± 0.006	0.008 ± 0.004	0.020 ± 0.013
<i>Chrysopsis gossypina</i>	0.061 ± 0.038	0.034 ± 0.037	0.050 ± 0.036	0.053 ± 0.032	0.236 ± 0.135
<i>Cnidoscolus stimulosus</i>	0.069 ± 0.010	0.052 ± 0.014	0.056 ± 0.017	0.086 ± 0.036	0.024 ± 0.022
<i>Commelina erecta</i>	0.016 ± 0.010	0.035 ± 0.010	0.014 ± 0.009	0.021 ± 0.011	0.005 ± 0.003
<i>Crataegus lacrimata</i>	0.050 ± 0.043	0.033 ± 0.041	0.091 ± 0.039	0.053 ± 0.036	0.017 ± 0.017
<i>Croton argyranthemus</i>	0.219 ± 0.040	0.346 ± 0.056	0.212 ± 0.074	0.253 ± 0.068	0.281 ± 0.089
<i>Danthonia sericea</i>	0.053 ± 0.024	0.043 ± 0.024	0.034 ± 0.023	0.014 ± 0.005	0.011 ± 0.006
<i>Dichanthelium</i> spp.	0.533 ± 0.064	0.612 ± 0.064	0.527 ± 0.073	0.645 ± 0.074	1.025 ± 0.131
<i>Eriogonum tomentosum</i>	0.069 ± 0.016	0.061 ± 0.024	0.052 ± 0.023	0.075 ± 0.024	0.122 ± 0.039
<i>Eupatorium compositifolium</i>	0.008 ± 0.005	0.013 ± 0.005	0.003 ± 0.003	0.020 ± 0.015	0.411 ± 0.176
<i>Euphorbia discoidalis</i>	0.001 ± 0.001	0.006 ± 0.001	0.004 ± 0.002	0.017 ± 0.010	0.055 ± 0.033
<i>Euphorbia floridana</i>	0.130 ± 0.044	0.092 ± 0.050	0.094 ± 0.030	0.103 ± 0.022	0.116 ± 0.033
<i>Galactia floridana</i>	0.368 ± 0.164	0.438 ± 0.160	0.487 ± 0.200	0.501 ± 0.192	0.979 ± 0.354
<i>Gaylussacia dumosa</i>	13.340 ± 4.822	18.016 ± 5.389	6.567 ± 2.914	9.570 ± 2.596	8.382 ± 2.327
<i>Hypoxis juncea</i>	0.030 ± 0.018	0.046 ± 0.019	0.031 ± 0.010	0.057 ± 0.019	0.069 ± 0.022
<i>Leptoloma cognatum</i>	0.014 ± 0.007	0.007 ± 0.006	0.005 ± 0.003	0.010 ± 0.007	0.104 ± 0.066
<i>Liatris</i> spp.	0.037 ± 0.014	0.051 ± 0.014	0.027 ± 0.008	0.062 ± 0.017	0.236 ± 0.146
<i>Licania michauxii</i>	5.336 ± 0.893	9.028 ± 1.008	5.572 ± 1.056	3.767 ± 0.427	8.843 ± 2.592
<i>Lupinus diffusus</i>	0.011 ± 0.004	0.012 ± 0.004	0.008 ± 0.005	0.009 ± 0.006	0.017 ± 0.015
<i>Opuntia humifusa</i>	0.000 ± 0.000	0.003 ± 0.000	0.003 ± 0.002	0.001 ± 0.001	0.003 ± 0.002
<i>Panicum virgatum</i>	0.013 ± 0.009	0.049 ± 0.009	0.025 ± 0.008	0.105 ± 0.035	0.336 ± 0.213
<i>Paspalum setaceum</i>	0.030 ± 0.009	0.030 ± 0.009	0.018 ± 0.009	0.031 ± 0.012	0.043 ± 0.011
<i>Pinus palustris</i>	0.172 ± 0.072	0.460 ± 0.066	0.171 ± 0.043	0.365 ± 0.215	1.116 ± 0.341
<i>Pityopsis aspera</i>	0.135 ± 0.070	0.248 ± 0.066	0.180 ± 0.053	0.244 ± 0.090	2.099 ± 1.340
<i>Pityopsis graminifolia</i>	0.001 ± 0.001	0.000 ± 0.009	0.009 ± 0.009	0.017 ± 0.017	3.475 ± 2.692
<i>Polygonella gracilis</i>	0.397 ± 0.173	0.610 ± 0.170	0.427 ± 0.179	0.447 ± 0.303	0.833 ± 0.635
<i>Pteridium aquilinum</i>	0.573 ± 0.231	0.499 ± 0.163	0.263 ± 0.101	0.210 ± 0.055	0.138 ± 0.071
<i>Quercus geminata</i>	0.427 ± 0.054	0.189 ± 0.409	0.684 ± 0.432	1.353 ± 0.808	1.307 ± 0.762
<i>Rhynchosia cytisoides</i>	0.138 ± 0.046	0.212 ± 0.062	0.162 ± 0.053	0.138 ± 0.048	0.095 ± 0.030
<i>Rhynchospora grayi</i>	0.234 ± 0.055	0.242 ± 0.058	0.180 ± 0.048	0.174 ± 0.036	0.177 ± 0.033
<i>Schizachyrium scoparium</i>	1.100 ± 0.240	1.624 ± 0.263	0.931 ± 0.231	1.508 ± 0.440	1.945 ± 0.361
<i>Schizachyrium tenerum</i>	0.094 ± 0.033	0.076 ± 0.026	0.143 ± 0.048	0.115 ± 0.029	0.120 ± 0.029
<i>Schrankia microphylla</i>	0.029 ± 0.011	0.039 ± 0.015	0.049 ± 0.021	0.043 ± 0.020	0.022 ± 0.012

Table 3.13. Continued.

Species	Treatment				Reference
	Control	ULW®	Burn	Felling	
<i>Scleria ciliata</i>	0.065 ± 0.030	0.057 ± 0.030	0.034 ± 0.013	0.095 ± 0.028	0.318 ± 0.130
<i>Serenoa repens</i>	0.102 ± 0.049	0.114 ± 0.045	0.110 ± 0.055	0.086 ± 0.035	0.125 ± 0.049
<i>Smilax auriculata</i>	1.944 ± 0.446	1.469 ± 0.274	3.775 ± 1.327	1.432 ± 0.356	0.351 ± 0.126
<i>Solidago odora</i>	0.048 ± 0.018	0.060 ± 0.015	0.089 ± 0.039	0.220 ± 0.114	1.669 ± 0.959
<i>Sorghastrum secundum</i>	0.065 ± 0.016	0.045 ± 0.015	0.051 ± 0.008	0.060 ± 0.013	0.036 ± 0.013
<i>Sporobolus junceus</i>	0.384 ± 0.051	0.453 ± 0.074	0.216 ± 0.041	0.521 ± 0.153	0.260 ± 0.081
<i>Stylisma patens</i>	0.170 ± 0.044	0.181 ± 0.050	0.190 ± 0.070	0.238 ± 0.065	0.262 ± 0.049
<i>Stylosanthes biflora</i>	0.004 ± 0.003	0.007 ± 0.003	0.003 ± 0.003	0.010 ± 0.006	0.070 ± 0.031
<i>Tephrosia chrysophylla</i>	0.048 ± 0.018	0.019 ± 0.013	0.038 ± 0.017	0.073 ± 0.033	0.072 ± 0.030
<i>Tephrosia mohrii</i>	0.335 ± 0.335	0.967 ± 0.535	1.612 ± 0.993	0.231 ± 0.223	1.500 ± 0.816
<i>Tradescantia hirsutiflora</i>	0.021 ± 0.006	0.045 ± 0.004	0.018 ± 0.007	0.014 ± 0.005	0.009 ± 0.002
<i>Tragia smallii</i>	0.012 ± 0.007	0.117 ± 0.007	0.050 ± 0.034	0.216 ± 0.111	0.100 ± 0.061
<i>Tragia urens</i>	0.023 ± 0.013	0.037 ± 0.026	0.042 ± 0.026	0.020 ± 0.009	0.070 ± 0.018
<i>Triplasis americana</i>	0.175 ± 0.058	0.096 ± 0.057	0.144 ± 0.042	0.158 ± 0.049	0.057 ± 0.032
<i>Vaccinium darrowii</i>	0.380 ± 0.227	1.040 ± 0.234	0.539 ± 0.350	0.621 ± 0.380	1.861 ± 1.216
<i>Yucca flaccida</i>	0.021 ± 0.006	0.020 ± 0.005	0.019 ± 0.004	0.016 ± 0.007	0.048 ± 0.014
Fall 1996					
<i>Ageratina aromatica</i>	0.000 ± 0.000	0.000 ± 0.001	0.001 ± 0.001	0.013 ± 0.009	0.289 ± 0.136
<i>Andropogon gyrans</i>	0.341 ± 0.114	0.224 ± 0.124	0.220 ± 0.068	0.285 ± 0.093	0.409 ± 0.100
<i>Andropogon ternarius</i>	0.038 ± 0.014	0.056 ± 0.013	0.041 ± 0.011	0.060 ± 0.018	0.022 ± 0.007
<i>Andropogon virginicus</i>	0.358 ± 0.117	0.215 ± 0.132	0.167 ± 0.049	0.107 ± 0.032	1.824 ± 0.508
<i>Anthraenantia villosa</i>	0.030 ± 0.022	0.017 ± 0.022	0.059 ± 0.038	0.010 ± 0.007	0.010 ± 0.007
<i>Aristida beyrichiana</i>	0.000 ± 0.000	0.000 ± 0.010	0.010 ± 0.010	0.445 ± 0.386	0.947 ± 0.661
<i>Aristida mohrii</i>	0.236 ± 0.065	0.164 ± 0.070	0.172 ± 0.053	0.122 ± 0.037	0.103 ± 0.039
<i>Aristida purpurescens</i>	0.280 ± 0.095	0.259 ± 0.083	0.305 ± 0.042	0.199 ± 0.083	0.201 ± 0.052
<i>Balduina angustifolia</i>	0.108 ± 0.043	0.092 ± 0.063	0.194 ± 0.067	0.144 ± 0.071	0.581 ± 0.488
<i>Chrysopsis gossypina</i>	0.059 ± 0.036	0.017 ± 0.034	0.042 ± 0.031	0.044 ± 0.023	0.324 ± 0.217
<i>Cnidoscolus stimulosus</i>	0.087 ± 0.025	0.034 ± 0.029	0.086 ± 0.028	0.098 ± 0.058	0.012 ± 0.012
<i>Commelina erecta</i>	0.042 ± 0.015	0.075 ± 0.013	0.029 ± 0.007	0.014 ± 0.006	0.010 ± 0.004
<i>Crataegus lacrimata</i>	0.057 ± 0.051	0.021 ± 0.037	0.095 ± 0.037	0.065 ± 0.041	0.020 ± 0.014
<i>Croton argyranthemus</i>	0.237 ± 0.032	0.249 ± 0.037	0.225 ± 0.043	0.263 ± 0.086	0.335 ± 0.086
<i>Danthonia sericea</i>	0.037 ± 0.021	0.030 ± 0.023	0.027 ± 0.023	0.012 ± 0.007	0.000 ± 0.000
<i>Dichanthelium</i> spp.	0.774 ± 0.141	0.581 ± 0.176	1.547 ± 0.201	1.106 ± 0.278	1.142 ± 0.225
<i>Eriogonum tomentosum</i>	0.056 ± 0.012	0.043 ± 0.020	0.073 ± 0.025	0.061 ± 0.021	0.122 ± 0.043
<i>Eupatorium compositifolium</i>	0.011 ± 0.006	0.024 ± 0.011	0.026 ± 0.015	0.021 ± 0.013	0.305 ± 0.086
<i>Euphorbia discoidalis</i>	0.000 ± 0.000	0.008 ± 0.009	0.012 ± 0.009	0.016 ± 0.009	0.082 ± 0.054
<i>Euphorbia floridana</i>	0.121 ± 0.024	0.055 ± 0.031	0.073 ± 0.022	0.065 ± 0.011	0.154 ± 0.039
<i>Galactia floridana</i>	0.395 ± 0.059	0.292 ± 0.082	0.727 ± 0.209	0.490 ± 0.197	2.127 ± 0.751
<i>Gaylussacia dumosa</i>	8.511 ± 2.351	8.280 ± 2.784	4.045 ± 1.391	5.894 ± 1.342	7.111 ± 2.379
<i>Hypoxis juncea</i>	0.030 ± 0.007	0.077 ± 0.004	0.028 ± 0.004	0.032 ± 0.007	0.142 ± 0.044
<i>Leptoloma cognatum</i>	0.013 ± 0.005	0.021 ± 0.004	0.008 ± 0.003	0.016 ± 0.008	0.025 ± 0.008
<i>Liatis</i> spp.	0.081 ± 0.015	0.052 ± 0.016	0.232 ± 0.081	0.190 ± 0.108	0.815 ± 0.249
<i>Licania michauxii</i>	4.642 ± 0.657	5.362 ± 0.701	4.742 ± 0.665	3.354 ± 0.322	6.199 ± 1.604

Table 3.13. Continued.

Species	Treatment				Reference
	Control	ULW*	Bum	Felling	
<i>Lupinus diffusus</i>	0.016 ± 0.009	0.005 ± 0.026	0.197 ± 0.120	0.184 ± 0.167	0.044 ± 0.040
<i>Opuntia humifusa</i>	0.001 ± 0.001	0.007 ± 0.002	0.008 ± 0.002	0.003 ± 0.003	0.005 ± 0.003
<i>Panicum virgatum</i>	0.013 ± 0.009	0.024 ± 0.008	0.030 ± 0.009	0.117 ± 0.048	0.560 ± 0.349
<i>Paspalum setaceum</i>	0.023 ± 0.008	0.018 ± 0.010	0.026 ± 0.008	0.031 ± 0.006	0.030 ± 0.010
<i>Pinus palustris</i>	0.085 ± 0.028	0.282 ± 0.026	0.059 ± 0.013	0.195 ± 0.135	0.203 ± 0.057
<i>Pityopsis aspera</i>	0.163 ± 0.044	0.106 ± 0.047	0.140 ± 0.064	0.178 ± 0.067	3.137 ± 1.619
<i>Pityopsis graminifolia</i>	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.014 ± 0.014	2.844 ± 1.930
<i>Polygonella gracilis</i>	1.257 ± 0.469	1.402 ± 0.490	0.298 ± 0.186	1.268 ± 0.731	0.367 ± 0.194
<i>Pteridium aquilinum</i>	1.042 ± 0.283	2.244 ± 0.663	1.689 ± 0.684	1.826 ± 0.565	1.307 ± 0.978
<i>Quercus geminata</i>	0.532 ± 0.051	0.090 ± 0.445	0.943 ± 0.466	1.425 ± 0.648	1.320 ± 0.782
<i>Rhynchosia cytisoides</i>	0.238 ± 0.044	0.173 ± 0.047	0.178 ± 0.043	0.214 ± 0.032	0.241 ± 0.059
<i>Rhynchospora grayi</i>	0.227 ± 0.050	0.087 ± 0.050	0.165 ± 0.035	0.160 ± 0.033	0.184 ± 0.034
<i>Schizachyrium scoparium</i>	1.464 ± 0.212	1.653 ± 0.266	0.944 ± 0.126	1.728 ± 0.533	2.931 ± 0.834
<i>Schizachyrium tenerum</i>	0.095 ± 0.036	0.055 ± 0.020	0.157 ± 0.044	0.140 ± 0.051	0.116 ± 0.030
<i>Schrankia microphylla</i>	0.035 ± 0.009	0.024 ± 0.007	0.042 ± 0.013	0.038 ± 0.011	0.035 ± 0.016
<i>Scleria ciliata</i>	0.061 ± 0.020	0.027 ± 0.021	0.056 ± 0.012	0.074 ± 0.026	0.499 ± 0.195
<i>Serenoa repens</i>	0.099 ± 0.059	0.134 ± 0.056	0.130 ± 0.068	0.083 ± 0.039	0.133 ± 0.063
<i>Smilax auriculata</i>	1.841 ± 0.535	1.207 ± 0.235	2.978 ± 0.965	1.104 ± 0.230	0.381 ± 0.126
<i>Solidago odora</i>	0.077 ± 0.042	0.021 ± 0.036	0.287 ± 0.142	0.197 ± 0.070	1.377 ± 0.508
<i>Sorghastrum secundum</i>	0.042 ± 0.008	0.055 ± 0.005	0.045 ± 0.009	0.059 ± 0.015	0.027 ± 0.013
<i>Sporobolus junceus</i>	0.336 ± 0.052	0.273 ± 0.074	0.145 ± 0.031	0.401 ± 0.124	0.152 ± 0.027
<i>Stylisma patens</i>	0.155 ± 0.014	0.066 ± 0.023	0.159 ± 0.042	0.151 ± 0.028	0.287 ± 0.034
<i>Stylosanthes biflora</i>	0.005 ± 0.004	0.005 ± 0.004	0.005 ± 0.003	0.012 ± 0.008	0.107 ± 0.056
<i>Tephrosia chrysophylla</i>	0.040 ± 0.010	0.038 ± 0.011	0.087 ± 0.018	0.075 ± 0.019	0.092 ± 0.032
<i>Tephrosia mohrii</i>	0.586 ± 0.586	0.536 ± 0.650	1.501 ± 0.780	0.359 ± 0.347	1.787 ± 0.900
<i>Tradescantia hirsutiflora</i>	0.012 ± 0.004	0.012 ± 0.004	0.013 ± 0.007	0.012 ± 0.006	0.018 ± 0.007
<i>Tragia smallii</i>	0.012 ± 0.006	0.051 ± 0.005	0.031 ± 0.022	0.160 ± 0.090	0.081 ± 0.052
<i>Tragia urens</i>	0.060 ± 0.028	0.029 ± 0.074	0.124 ± 0.075	0.041 ± 0.017	0.221 ± 0.062
<i>Triplasis americana</i>	0.159 ± 0.058	0.076 ± 0.040	0.100 ± 0.033	0.156 ± 0.060	0.046 ± 0.046
<i>Vaccinium darrowii</i>	0.260 ± 0.140	0.735 ± 0.144	0.499 ± 0.318	0.535 ± 0.306	1.444 ± 0.754
<i>Yucca flaccida</i>	0.017 ± 0.005	0.022 ± 0.003	0.022 ± 0.005	0.018 ± 0.007	0.066 ± 0.020

Table 3.14. Summary of significant fall 1995 and fall 1996 (post treatment) effects of hardwood reduction techniques on plant and tree variables. Adjusted values from each treatment were ranked from highest to lowest. Inequality signs are only presented for significant contrasts. The “?” sign indicates an uncertain outcome for an untested contrast. Pre-treatment effects were factored out of these summary results.

Variable	Fall 1995	Fall 1996
	Highest ↔ Lowest	Highest ↔ Lowest
Canopy and midstory structure and composition		
Proportion of canopy cover	$C > B = ULW^* > F/G^\dagger$	$C = B = ULW^* = F/G$
Longleaf pine		
Density	$C = ULW^* = F/G > B$...‡
Basal area	$ULW^* = F/G = B = C$	...
Sand live oak		...
Density	$C > B = ULW^* > F/G$	...
Basal area	$B > C = ULW^* = F/G$	...
Turkey oak		...
Density	$C > B = ULW^* > F/G$	...
Basal area	$C > B > ULW^* > F/G$	...
Proportion of cover of understory plant and woody residue		
Graminoids	$C = B = F/G > ULW^*$	$ULW^* > B = F/G > C$
Forbs	$B > ULW^* = F/G = C$	$ULW^* = B = F/G = C$
Fine litter	$ULW^* = F/G ? C > B$	$ULW^* = F/G ? C > B$
Woody species	$C > B = F/G > ULW^*$	$B > C = F/G ? ULW^*$
Woody litter	$F/G > C = ULW^* > B$	$F/G > B > ULW^* > C$
Density of understory plant species		
Plant species richness	$B = C = F/G = ULW^*$	$B > F/G = C = ULW^*$
Graminoids	$C > F/G = ULW^* = B$	$B > C = F/G > ULW^*$
Longleaf pine juveniles	$ULW^* = C = F/G > B$	$ULW^* = C = F/G > B$
Trees (<1.4 m high)	$F/G = B > C > ULW^*$	$B = ULW^* = C > F/G$
Woody vines	$C ? ULW^* > B = F/G$	$C = ULW^* = F/G = B$
Gopher apple	...§	$F/G > B = C > ULW^*$
Lopsided Indian grass	...	$ULW^* > F/G = B = C$
Low panic grasses	...	$B > F/G > C > ULW^*$
Pineywoods dropseed	...	$C > F/G = B > ULW^*$
Gray's beakrush	...	$C = B = F/G > ULW^*$
Wireweed	...	$C = F/G > ULW^* = B$
Yellow stargrass	...	$ULW^* > B = C = F/G$

† Treatments: B = burn; C = control; F/G = felling/girdling; ULW^* = herbicide.

‡ ... = trees not sampled during the winter 1996/1997.

§ ... = data not presented because treatment application immediately preceded sampling, and species had not experienced a full reproductive cycle in response to treatments.

4. INITIAL POST-HARVESTING EFFECTS OF SAND PINE REMOVAL ON PLANTS IN SANDHILLS AT EGLIN AIR FORCE BASE, FLORIDA

ABSTRACT

The purpose of this study was to document the impact of sand pine (*Pinus clausa*) removal on groundcover plant species richness and densities before and two years post-removal. We also measured the survivorship of planted longleaf pine (*Pinus palustris*) seedlings one year after planting. Plant species richness decreased by eight species per 1600 m² on average compared to pre-harvest values during the first year post-removal, but plant species richness exceeded pre-treatment level two years post-harvest. Among the numerically important species, dwarf huckleberry (*Gaylussacia dumosa*) was the only taxon to show consistent decreases in density for two years post-harvest compared to pre-harvest levels. Broomsedge (*Andropogon virginicus*), little bluestem (*Schizachyrium scoparium*), gopher apple (*Licania michauxii*), pineland hoary-pea (*Tephrosia mohrii*), and sand pine had initially decreased in the post-harvest phase, but were modestly increasing two years following harvest. Low panic grasses (*Dichanthelium* spp.), wiregrass (*Aristida beyrichiana*), and Florida spurge (*Euphorbia floridana*) increased both years in the post-harvest period. Other species did not appreciably vary among years. On average, 78% of planted longleaf pine seedlings survived their first year in sand pine removal plots.

INTRODUCTION

In northwest Florida, the Choctawhatchee variety of sand pine (*Pinus clausa* [Chapm. ex Engelm.] Vasey ex Sarg. var. *immuginata* Ward) hereafter referred to as sand pine (Ward 1963; Parker and Hamrick 1996) is found in scrub on barrier islands, the coast, and inland in areas that have not burned for several years. The encroachment of sand pine in fire-suppressed or formerly harvested sandhills can be rapid because this variety has open cones that do not require fire for seed release, and it can produce viable seeds when as early as five years in age (USDA 1990). Sandhills where sand pine has successfully encroached at Eglin Air Force Base (EAFB) have recently been classified as Tier III sandhills by Florida Natural Areas Inventory (FNAI) (FNAI 1994 and 1995, Kindell et al. 1997). Tier III represents a highly degraded forest condition. These sand pine-dominated sandhills were classified as the "*Pinus palustris*-*Pinus clausa*/*Quercus laevis*/*Sporobolus junceus* Woodland Alliance" in The Nature Conservancy's *International Classification of Ecological Communities* (Weakly et al. 1998). Sand pine-dominated sandhills are characterized as having closed canopies with sparse occurrences of longleaf pine (*Pinus palustris*), dense subcanopies of sand pine, sand live oak (*Quercus geminata*) and turkey oak (*Q. laevis*), a sparse to moderate shrub layer, and a herbaceous groundcover that consists of less than 5% of native perennial grasses (FNAI 1994 and 1995, Provencher et al. 1996, Kindell et al. 1997).

A large area of southeastern EAFB was formerly longleaf pine-dominated sandhills (unpub. manuscript), but is now heavily dominated by sand pine (Kindell et al. 1997). Verbal testimony from long-retired EAFB foresters and historical photography from the 1940's (property of EAFB) suggests that long leaf pine was harvested from most southeastern sandhills during the beginning of the century and managed for sand pine production.

Unlike the more conventional method of employing prescribed fire to restore sandhill communities dominated by midstory hardwoods, restoration of sand pine-dominated sandhills requires more intensive methods. Prescribed fire usually will not carry through such dense sand pine stands, and large individuals can resist scorching of the bole. Fires of sufficient intensity to kill the sand pines are difficult to control. Mechanical removal of sand pine on a

commercial scale, with fuel chipping or harvesting operations, is the best alternative. These methods open up the canopy and generate revenues which can be used for future restoration projects. The major disadvantages of mechanical removal are the intensive impact to understory species, soil compaction and rutting caused by heavy machinery (skidders, tractors, trucks, fuel chipper), and the possible introduction of exotic plant species such as Chinese tallow tree (*Sapium sebiferum*), cogon grass (*Imperata cylindrica*) and Bahia grass (*Paspalum notatum*) carried by contaminated machinery or other agents (Kindell et al. 1997).

The purpose of this study was to document the impact of mechanical removal of sand pine on groundcover plant species richness and densities. Measurements were therefore collected before removal and two years post-removal. We also measured the survivorship of planted longleaf pine seedlings one year after planting.

METHODS

Experimental Design

In sand pine removal sites, we assessed vegetation composition, densities, and structure before and after mechanical removal of sand pine. We replicated sand pine removal operations in six 81-ha (200-acre) square plots located in the southeastern part of EAFB (Fig. 4.1). Sites were selected in areas that had high densities of mature sand pine, but that still had mature and seed-bearing longleaf pine individuals present. We avoided plots that were potential sand pine-scrub oak communities.

Each 81-ha (200-acre) plot contained 32, 10 × 40-m sampling subplots. We strategically arranged subplots in four linear arrays to examine the rate of establishment of sand pine and exotic species from the corners (periphery) to the center (core) of the square plots (Fig. 4.2). Because groups of four subplots were arranged in an "X", they ran from periphery to core. This arrangement was more strategic than statistical because these linear arrays are not blocks, as understood in experimental block design (Steel and Torrie 1980). In fact, one statistical block was formed by the four groups of four 10 × 40-m subplots at the periphery of the 81-ha (200-acre) plot, and the other block was comprised of the four groups of four subplots situated at the core of the plot. In order to test sampling distance effects, subplots were spaced in 10 and 50 m sampling distances with two of each distance per periphery and two in the core between adjacent subplots. These distance tests are not presented in this report.

Data Collection

We conducted one year of pre-treatment data collection from August 1994 to October 1994. Sand pine removal was done from January 1995 until July 1995. The first late summer/fall post-treatment vegetation sampling was performed in August 1995. The first winter, post-treatment tree (DBH and height) sampling spanned from December 1995 until January 1996. The second post-treatment sampling was conducted during the same dates, but one year later. Fuel reduction burns were carried out in the six plots in the winter after the January 1996 post-treatment tree sampling. We have currently completed our third season of post-treatment sampling on these sites.

Understory vegetation densities were estimated by counting individual plants as stems or clumps for graminoids (grasses and sedges) in four 0.5 × 2-m sub-subplots situated in the corners of each 10 × 40-m subplot (Fig. 4.2). All woody and non-woody plants (<1.4 m high) with >50% of the stems rooted within each sub-subplot were counted. Highly abundant species were assigned to density classes: I = 1-5; II = 6-10; III = 11-25; IV = 26-50; V = 51-100; VI = 101-150; and VII = >151 individuals. Plant species that were assigned density classes were: Darrow's blueberry (*Vaccinium darrowii*), dwarf huckleberry (*Gaylussacia dumosa*), gopher apple (*Licania michauxii*), grass-leaf golden aster (*Pityopsis graminifolia*),

and pineland hoary-pea (*Tephrosia mohrii*). For bunch grasses and forbs, clumps separated by >10 cm were considered separate, distinct plants. For all species, the number of flowering stems or clumps was also recorded. A "walk-through" of the 10 × 40-m plot was conducted for a maximum of 10 minutes to record the identity of all plant species present.

Statistical Analyses

We graphed the pre- and post-treatment average whole-plot median, 25 and 75% quartiles, and minimum and maximum values of plant species richness, and the variables of 12 more common plant species. (Fifty percent of values are smaller or greater than the median. The 25 and 75% quartiles contain the central 50% of the data values; therefore, data from three of six plots closest to the median are contained within the 25 and 50% quartiles.) We chose to graph the median and 25 and 75% quartiles because they show the actual distribution of the data. Otherwise, we tabulated the mean and standard error of the densities of other plant species.

We also regressed the density of longleaf pine seedlings from the 1996 sample against the density of longleaf pine planted in 1995. Practically all counted seedlings were those that had been planted, because pre-treatment seedling density was virtually null, and the fall 1996 seedling crop did not contribute new seedlings in sampled sub-subplots (although a few zones of natural regeneration were observed in 81-ha [200-acre] plots). It should be remembered that the pre-treatment density of mature longleaf pine was low in all plots (Provencher et al. 1996). Importantly, the slope of the regression line should estimate seedling survival rate during one year.

RESULTS

A checklist of all plant taxa encountered from spring 1994 through fall 1996 in the sand pine removal plots is presented together with taxa that were documented in the restoration plots (see Chapter 3) in Appendix A. For the most part, plant species composition was similar between the two experiments, suggesting similar original community types. Some plant taxa that were found only in the sand pine removal plots included: peanut (*Arachis hypogaea*), coast sandspur (*Cenchrus incertus*), common ragweed (*Ambrosia artemisiifolia*), Bahia grass, and Chinese tallow tree. A total of 349 taxa representing 72 families and 187 genera was documented (Provencher et al. 1996 and 1997, Rodgers and Provencher, *in press*).

The pre-treatment median number of plant (trees and groundcover) species was slightly less than 52/1600 m² (Fig. 4.3). A few months after sand pine removal, species richness dropped to 42/1600 m² and quartile distributions did not overlap with pre-treatment values. Two years post-removal, the number of species increased to slightly over 52/1600 m². There was substantial overlap between the 1994 and 1996 quartile distributions. Of the 58 more common species presented in Table 4.1, only nine were not observed in all years. Therefore, shifts in abundance of less common species most accounted for temporal changes in plant species richness.

Three graminoid species or genera were abundant in at least one year (Fig. 4.4): broomsedge (*Andropogon virginicus*), low panic grasses (*Dichanthelium* spp.), and little bluestem (*Schizachyrium scoparium*). The median density of broomsedge was relatively stable among years and never more than 0.025 clumps/m² (Fig. 4.4). However, the mean density of broomsedge became very close to 0 in 1995 and increased to 0.35 clumps/m² in some plots in 1996. The median density of low panic grasses progressively increased from 0.3 clumps/m² in 1994 to 1.5 clumps/m² in 1996 (Fig. 4.4). This group of species, which was dominated by egg-leaf panic grass (*Dichanthelium ovale*), was the most abundant of all taxa over these years. The median density of little bluestem decreased from 0.1 clumps/m² in 1994 to 0.05 clumps/m² in 1995, but then slightly increased to 0.075 clumps/m² in 1996 (Fig. 4.4). A fourth grass species, wiregrass (*Aristida beyrichiana*), was also followed because of its conservation

significance. Wiregrass was not detected in 1994, but densities progressively increased from 1995 to 1996 (Fig. 4.4).

Densities of three forbs and one tree (<1.4 m high) species are presented in Fig. 4.5. The median density of Florida spurge (*Euphorbia floridana*) increased linearly from 0.075 stems/m² in 1994 to 0.2 stems/m² in 1996 (Fig. 4.5). On the other hand, the density of Florida milk-pea (*Galactia floridana*) barely changed from 0.2 to 0.16 stems/m² among years (Fig. 4.5). The median density of pineland hoary-pea decreased from 0.06 in 1994 to 0.03 stems/m² in 1995 and then increased back to 0.06 stems/m² in 1996 (Fig. 4.5). For this latter year, the variability in density greatly increased. The median tree seedling density of sand pine started at 2.5 stems/m² in 1994 and decreased to approximately 0.1 stems/m² in 1995 and 1996 (Fig. 4.5).

Density data from all additional four woody shrubs, vines, and trees are presented in (Fig. 4.6). The median density of dwarf huckleberry progressively diminished from 0.21 stems/m² in 1994 to 0.09 stems/m² in 1996 (Fig. 4.6). Median gopher apple stems/m² decreased from 0.61 in 1994 to 0.3 in 1995, but then increased to 0.5 stems/m² in 1996 (Fig. 4.6). Sand live oak median density slightly increased from 0.09 in 1994 to 1.5 stems/m² in 1996 (Fig. 4.6). Median catbrier (*Smilax auriculata*) density varied from 0.7 stems/m² in 1994 to 0.55 stems/m² in 1995, and to 0.78 stems/m² in 1996 (Fig. 4.6).

The densities of longleaf pine juveniles were significantly correlated between 1995 and 1996 (correlation = 0.814; Fig. 4.7). The slope of the significant regression ($P < 0.000000$) was 0.78, thus the first year survivorship was 78%. Despite the high significance of the regression, many sample points were outside of the 95% confidence interval.

Two exotic plant species have been discovered in the sand pine removal plots: Chinese tallow tree and Bahia grass. Chinese tallow tree was first detected in two plots in 1996 and is still present today. Bahia grass has been present in most plots since fall 1994.

DISCUSSION

The first year effects of sand pine removal on plant species were mixed. (To provide the reader with a synthetic view of all significant results, the many treatment effects are summarized in Table 4.2). Plant species richness decreased (Fig. 4.3) by eight species on average. The densities of the numerically important species, dwarf huckleberry and little bluestem, also decreased. On the positive side, sand pine was greatly reduced (Fig. 4.5) and, surprisingly, wiregrass started recovering (Fig. 4.4). In both cases, fire and mechanical damage may have caused these effects. The second year picture was different because plant species richness exceeded pre-treatment levels, and several common species that had initially decreased were increasing in 1996 (Table 4.2) (e.g., broomsedge, little bluestem [Fig. 4.4], gopher apple [Fig. 4.6], and pineland hoary-pea [Fig. 4.5]). Dwarf huckleberry, however, continued to decline (Fig. 4.6). High mortality and slow recovery of *Gaylussacia* species following severe fire has been reported for the pine barrens of New Jersey and has been attributed to the shallow depth of their root systems and a mostly vegetative reproductive strategy (Matlack et al. 1993). It is easily conceived that heavy machinery negatively affected the roots of dwarf huckleberry.

Moore et al. (1982) reported short-term increases in species diversity due to disturbance effects on understory communities in southeastern pinelands and has concluded that the effects of harvesting are minimal. As we observed in a chronosequence of plots at EAFB (Provencher et al. 1996), this increased diversity may be attributed to the abundance of native ruderals and may not represent desired long-term site conditions. Greenberg et al. (1995) observed an increase in herbaceous ruderal species in sand pine scrub plots where Ocala sand pine (*Pinus clausa* [Chapm. ex Engelm. Vasey ex Sarg.] var. *clausa*) was removed by mechanical operations as compared to unharvested plots in the Ocala National Forest. Most native scrub

species were not, however, lost due to the removal of Ocala sand pine, presumably because those species have evolved traits to survive and reproduce following large-scale stand replacement caused by fires and hurricanes (Greenberg et al. 1995). Modern silvicultural activities, which usually include site-preparation techniques to reduce competition, often eliminate key species such as wiregrass and may lead to a dominance of weedy species (Grelen 1962, Conde et al. 1983, Noss 1989). In this study, mechanical site preparation other than slash reduction burns was excluded from forestry operations, which may explain why some annuals and wiregrass survived restoration treatments and benefited from subsequent burns.

An early low panic grass phase of succession was definitely observed in sand pine removal plots (Fig. 4.4, Table 4.2). Seeds of low panic grasses are typically large and usually dispersed by animals. Seeds may also have been dormant in the seedbed. Judging from other observations in recently disturbed sites in the southeastern U.S. (Grelen 1962, Moore et al. 1982, Campbell 1983, Conde et al. 1983, Provencher et al. 1996), we anticipate that broomsedge and dogfennel (*Eupatorium compositifolium*) will dominate the biomass and, maybe densities, of these plots. The rapid but patchy increase of broomsedge densities confirms this prediction (Fig. 4.4). A positive consequence for wildlife resulting from rapid colonization by low panic grasses and broomsedge is the availability of food and cover for northern bobwhite quail (*Colinus virginianus*) during the early vegetative recovery (Grelen 1961). Other birds, especially passerines, will likely forage and nest in these grassy habitats.

One of the potentially negative side effects of mechanical harvesting of sand pine was the potential introduction of exotic plant species, especially the very aggressive Chinese tallow tree, which is considered by The Nature Conservancy (TNC) to be one of the top 12 worst exotic species in the U.S. (TNC 1997b). It is also categorized by the Florida Exotic Pest Plant Council (EPPC) as a category I species, which defines it as one of the most aggressive and disruptive plants that occurs in Florida (EPPC 1995). In 1993, Chinese tallow tree was observed growing in 38 of Florida's 67 counties. It currently ranges from the eastern Gulf coast of Texas throughout Florida, north to the eastern coast of North Carolina (Jubinsky and Anderson 1996). Allowed to gain a foothold, this nuisance species can proliferate and displace native vegetation. Although contaminated logging machinery can be a source of exotic species invasion, bird dispersal may be the more likely vector for Chinese tallow tree (Jubinsky 1993). The introduction of the red imported fire ant (*Solenopsis invicta*) is also a consideration with site preparation and soil disturbance. Given the extent of sand pine removal and fuel chipping at EAFB, there is a greater likelihood for the introduction of exotics. Areas that have undergone sand pine removal need to be inspected and monitored. Once established, these exotic species are very difficult to eradicate.

Our data for survivorship of planted longleaf pine from containerized seedlings in Lakeland sand were similar to those found for bare-root plantings in disked, more argillic soil (Farrar and White 1983). We estimated survivorship rates at 78% for EAFB (Fig. 4.7), whereas Farrar and White (1983) obtained rates of 76%. Survivorship rates of containerized longleaf pine seedlings should be higher than bare-root within the same soil type, which justifies their higher costs (\$110/1000 containerized seedlings vs. \$55/1000 bare-root seedlings [M. Barber, Division of Forestry, *pers. comm.*]). However, survivorship rates vary greatly with soil type and yearly rainfall. At EAFB, we do not have published longleaf pine seedling survivorship records, but rates for containerized seedlings apparently vary between 70% to 80% (D. Gartman, Natural Resources Division, EAFB, *pers. comm.*). At The Nature Conservancy's Apalachicola Bluffs and Ravines Preserve in Liberty County, Florida, first year survivorship of containerized seedlings varies between 60% and 82% in Lakeland soil (G. Seamon, The Nature Conservancy, *pers. comm.*). At the preserve, survivorship appeared to depend mostly on rainfall and, to some degree, on logistical factors rather than ecological. Increased soil compaction by tree removal machinery could also be a cause of lower seedling survivorship in sand pine removal plots (Grant 1993). Miller and Donahue (1990) report that loblolly pine (*Pinus taeda*) seedlings, which are easier to regenerate than longleaf pine, experienced reduced

growth with increased bulk density (i.e., soil compaction). For optimal plant growth, bulk densities should be below 1.6 g/cm^3 for sandy soils (Miller and Donahue 1990). Therefore, increased bulk density should also affect the germination success of native understory species. Although we did not measure bulk density, metal poles were inserted into the substrate with ease prior to sand pine removal, but a greater effort had to be exerted to perform the same task post removal. (Soil compaction can be measured with appropriate equipment.) We expect seedlings that survived the first year following planting to exhibit high survivorship into the third year.

ISSUES OF MANAGEMENT CONCERN

The main point here for land managers is that sand pine removal will change plant community composition. Ruderal species will likely respond to soil disturbance as indicated by increases in low panic grasses and broomsedge densities. More importantly, exotic species have invaded the study plots, thus suggesting that managers should monitor other sand pine removal and fuel chipping sites for invasive species. We have also shown that artificial longleaf pine regeneration survival rates in sand pine removal plots were high despite sites' receiving minimal seedbed preparation other than fire. This result warrants further studies on longleaf pine regeneration.

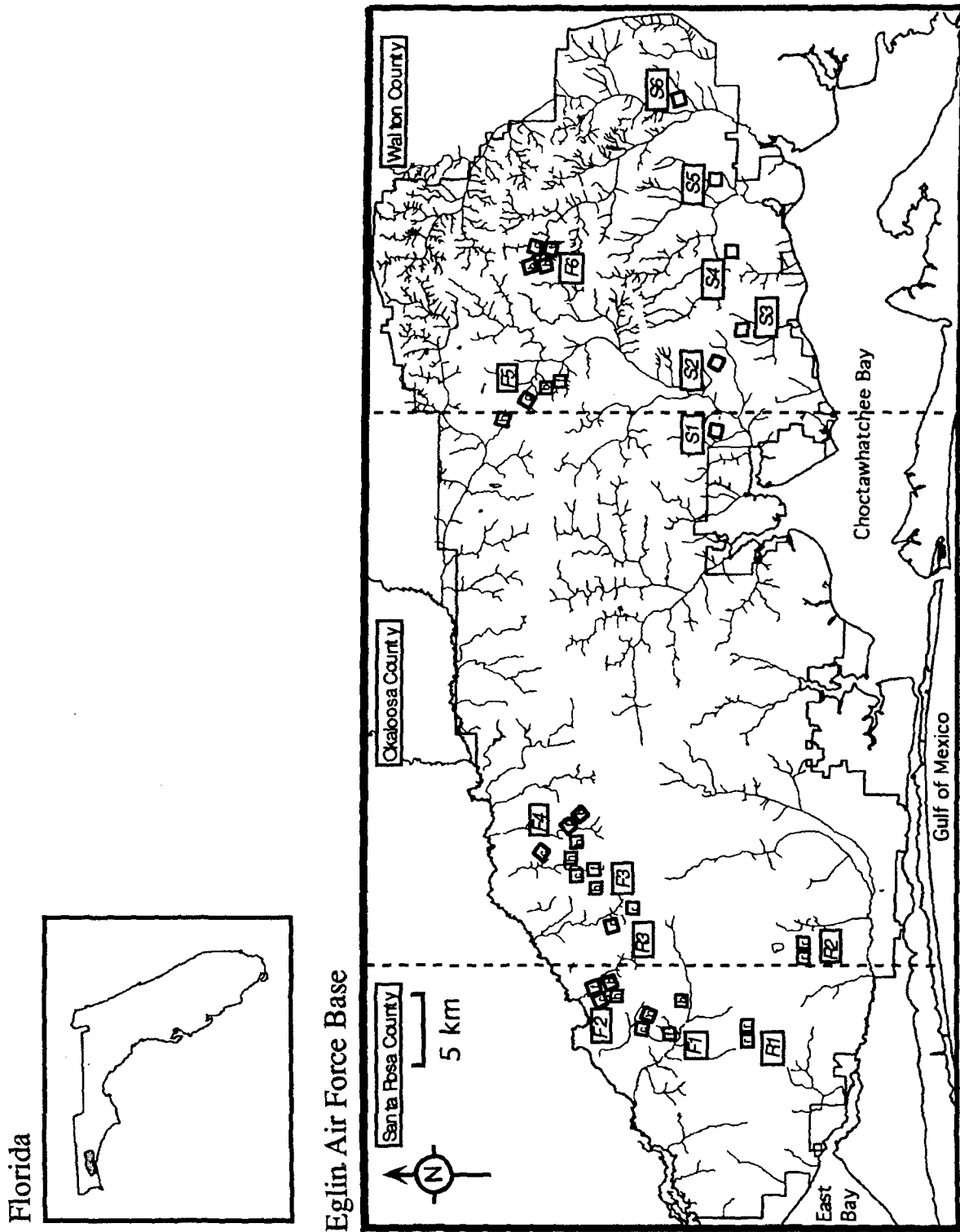


Fig. 4.1. Location of restoration (F), reference (R), and sand pine removal (S) plots on Eglin Air Force Base, Florida. Small squares represent 81-ha (200-acre) plots. Legend: b = burn; c = control; f = felling/girdling; h = herbicide; r = reference.

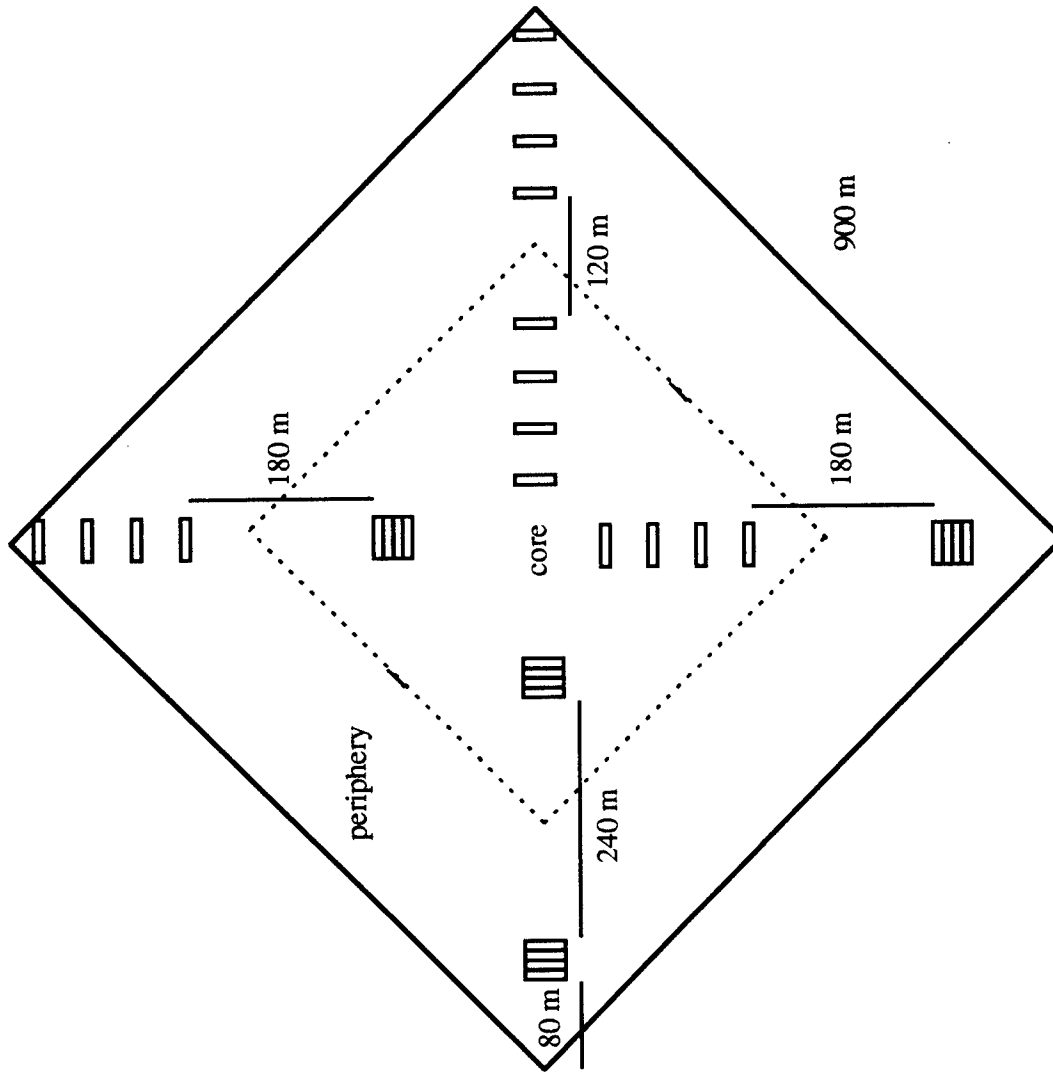


Fig. 4.2. Sand pine removal plot: layout of sampling step treatments in one of six plots. Each plot is comprised of peripheral and core areas (dotted line separates the core and peripheral areas). Sampling step is 10 and 50 m as in restoration experiment (see Chapter 3). Sub-subplot sampling is presented in Figure 3.3.

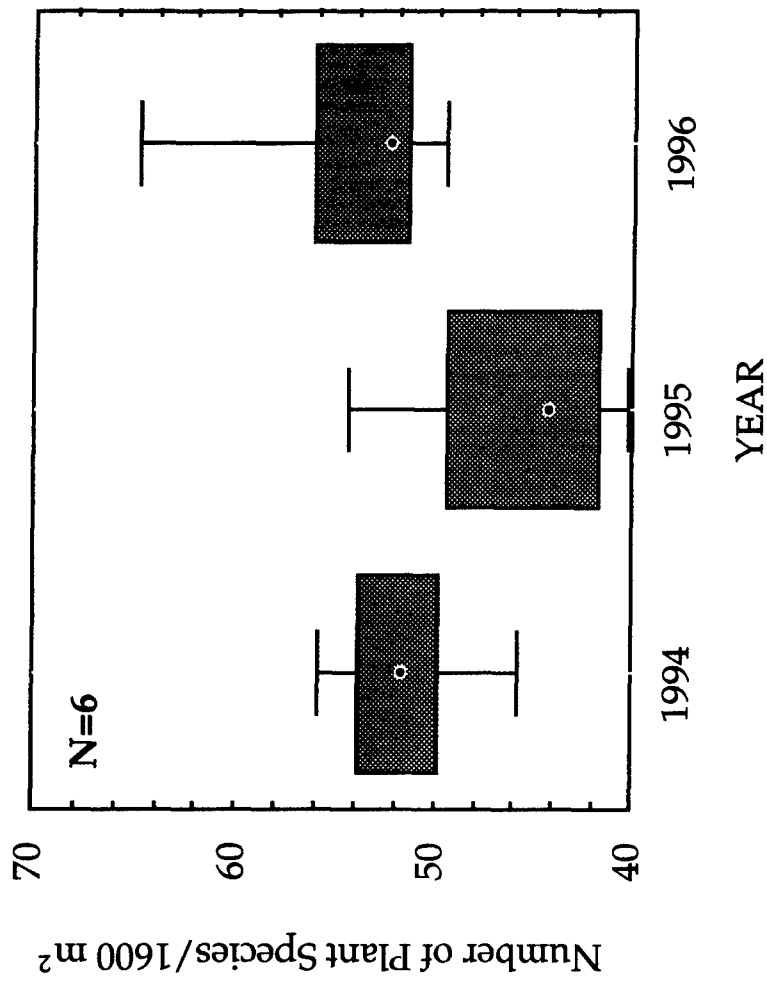


Fig. 4.3. Plant species richness in sand pine removal plots during pre- (1994) and post-removal years (1995 and 1996). Center of box represents the median (unadjusted to pre-treatment values), upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Sample size = 6.

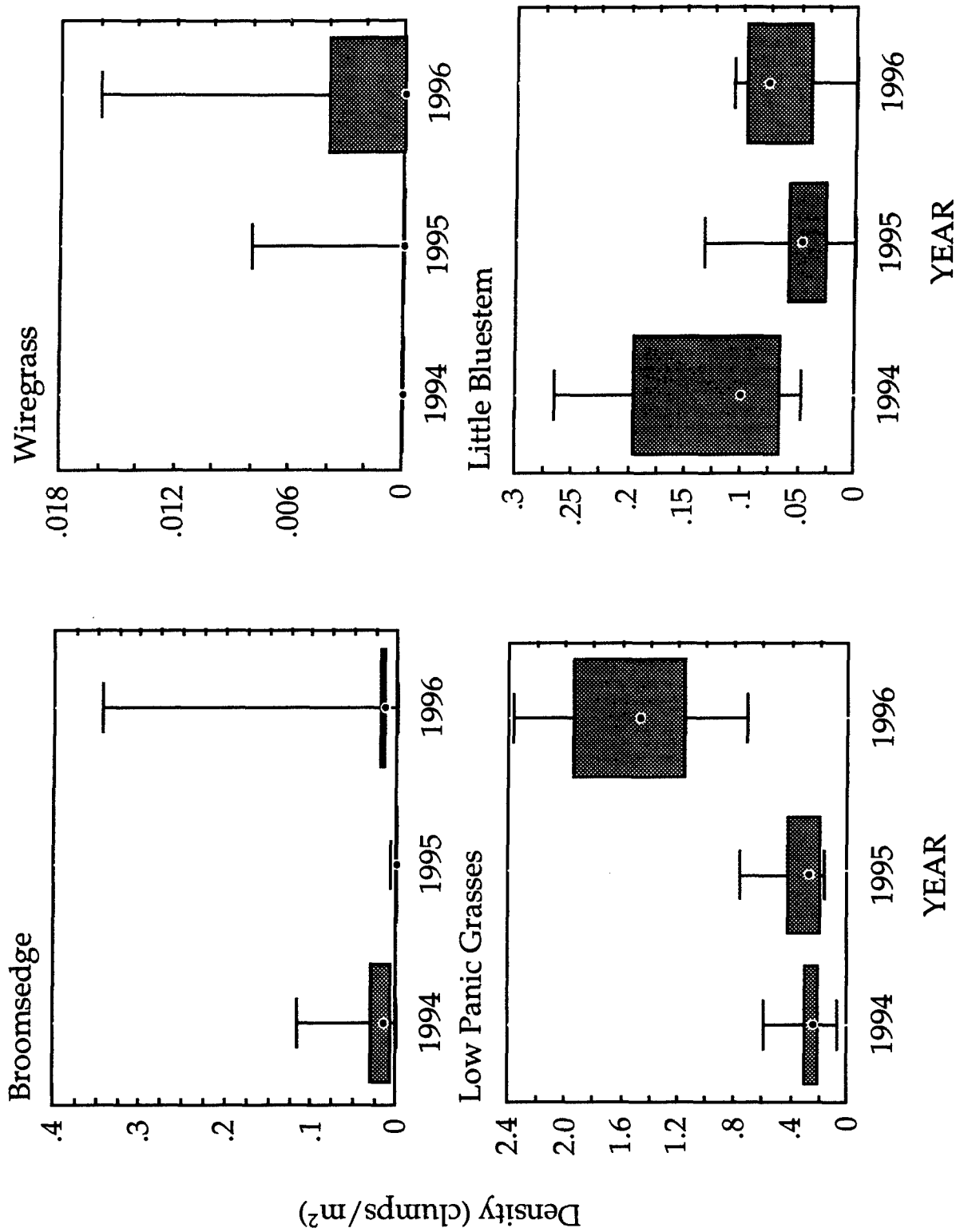


Fig. 4.4. Densities of broomsedge, wiregrass, low panic grasses, and little bluestem in sand pine removal plots during pre-treatment (1994) and post-treatment years (1995 and 1996). Center of box represents the median (unadjusted to pre-treatment values), upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Sample size = 6.

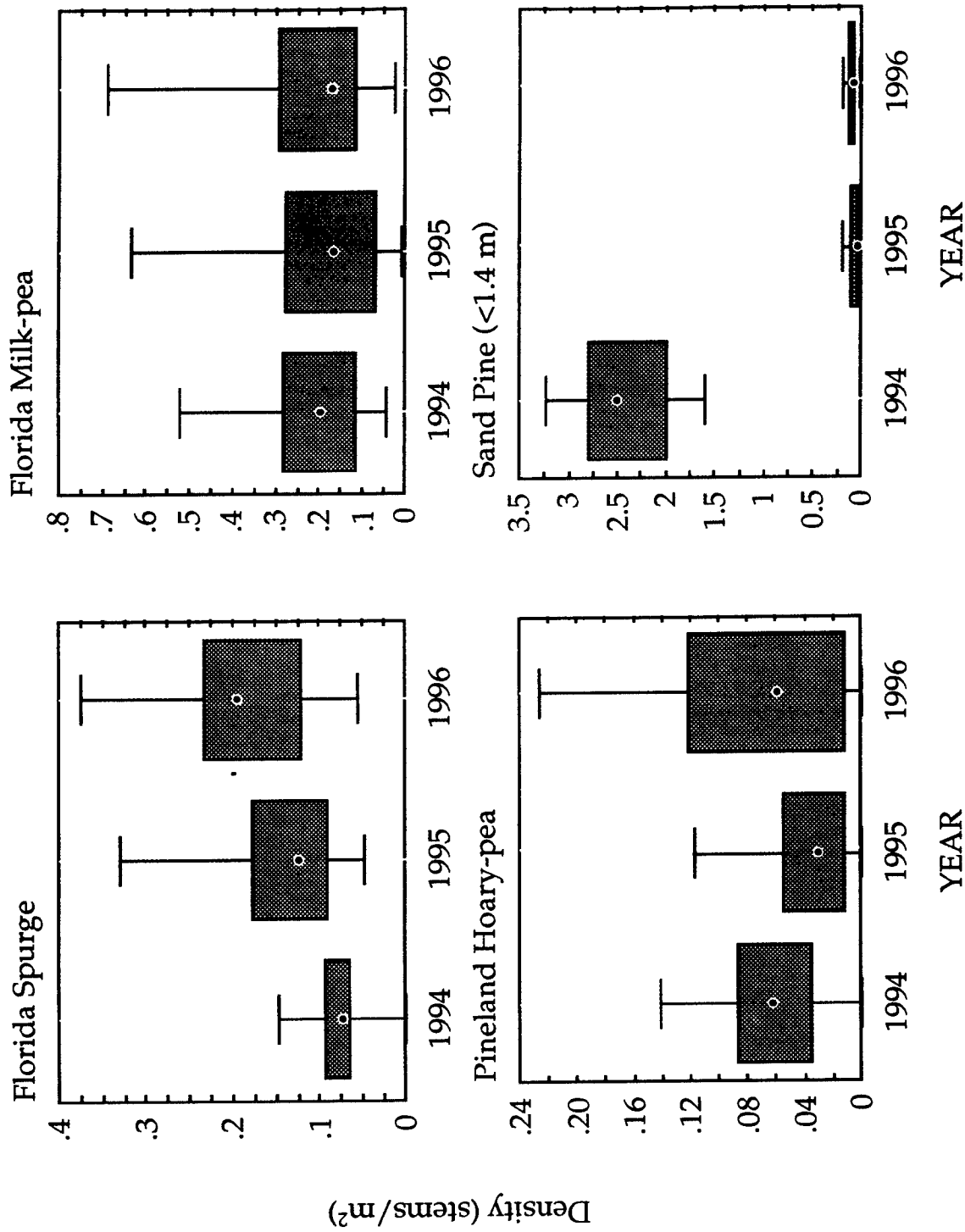


Fig. 4.5. Densities of Florida spurge, Florida milk-pea, pineland hoary-pea, and sand pine in sand pine removal plots during pre- (1994) and post-removal years (1995 and 1996). Center of box represents the median (unadjusted to pre-treatment values), upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Sample size = 6.

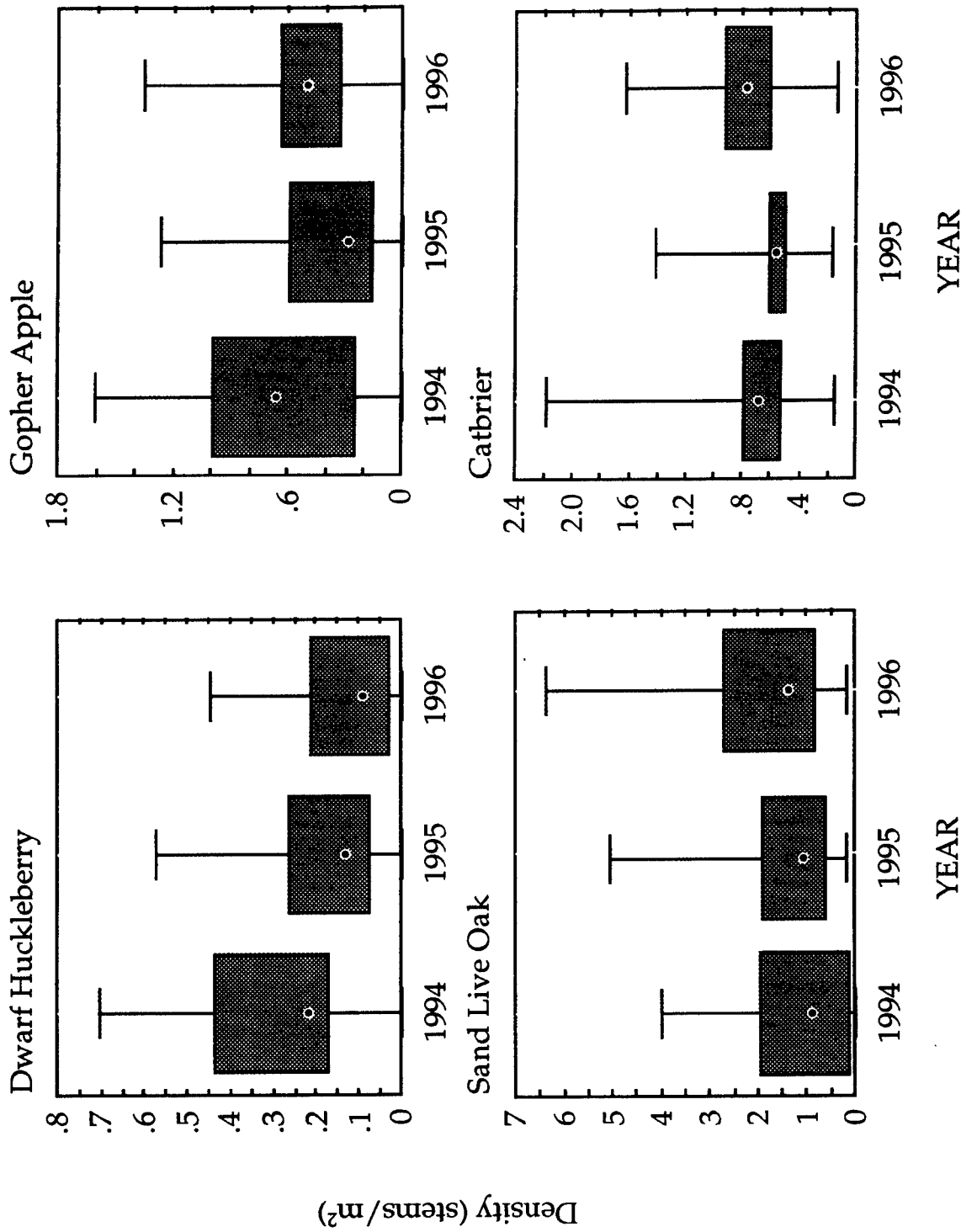
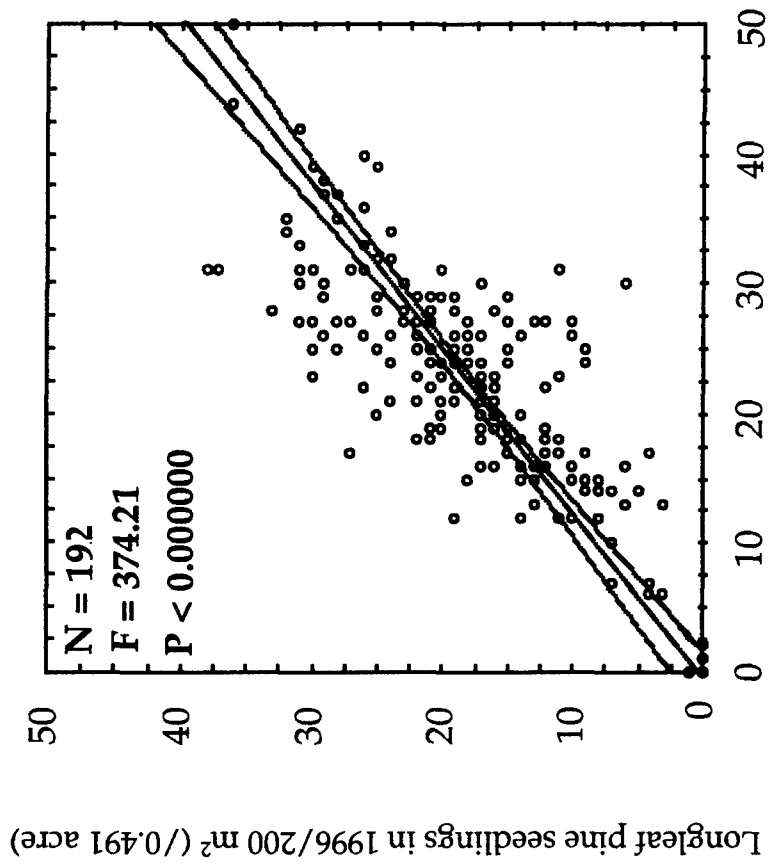


Fig. 4.6. Densities of dwarf huckleberry, gopher apple, sand live oak, and catbrier in sand pine removal plots during pre- (1994) and post-removal years (1995 and 1996). Center of box represents the median (unadjusted to pre-treatment values), upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Sample size = 6.

seedlings in 1996 = $0.52354 + 0.78327 * \text{seedlings in 1995}$

Correlation = 0.81440



Longleaf pine seedlings planted in 1995/200 m² (/0.491 acre)

Fig. 4.7. Survivorship of planted, containerized longleaf pine seedlings from 1995 to 1996 in sand pine removal plots.

SAND PINE REMOVAL

Table 4.1. Mean (± 1 standard error) of 58 common groundcover plant species densities (stems m^{-2}) in six 81-ha (200-acre) sand pine removal plots at Eglin Air Force Base, Florida. Sample size = 6 plots per year.

Species	Year		
	1994	1995	1996
<i>Ageratina aromatica</i>	0.000 \pm 0.000	0.000 \pm 0.000	0.000 \pm 0.000
<i>Andropogon gyrans</i>	0.065 \pm 0.019	0.005 \pm 0.004	0.009 \pm 0.006
<i>Andropogon ternarius</i>	0.004 \pm 0.002	0.008 \pm 0.005	0.005 \pm 0.004
<i>Andropogon virginicus</i>	0.033 \pm 0.018	0.001 \pm 0.001	0.069 \pm 0.055
<i>Anthaenanthia villosa</i>	0.000 \pm 0.000	0.001 \pm 0.001	0.000 \pm 0.000
<i>Aristida beyrichiana</i>	0.000 \pm 0.000	0.001 \pm 0.001	0.004 \pm 0.003
<i>Aristida mohrii</i>	0.016 \pm 0.007	0.005 \pm 0.003	0.005 \pm 0.002
<i>Aristida purpurescens</i>	0.108 \pm 0.034	0.004 \pm 0.002	0.017 \pm 0.005
<i>Balduina angustifolia</i>	0.000 \pm 0.000	0.000 \pm 0.000	0.043 \pm 0.025
<i>Chrysopsis gossypina</i>	0.000 \pm 0.000	0.000 \pm 0.000	0.001 \pm 0.001
<i>Cnidoscolus stimulosus</i>	0.027 \pm 0.013	0.016 \pm 0.006	0.026 \pm 0.012
<i>Commelina erecta</i>	0.003 \pm 0.003	0.001 \pm 0.001	0.000 \pm 0.000
<i>Crataegus lacrimata</i>	0.022 \pm 0.011	0.025 \pm 0.011	0.051 \pm 0.024
<i>Croton argyranthemus</i>	0.042 \pm 0.029	0.022 \pm 0.013	0.025 \pm 0.011
<i>Danthonia sericea</i>	0.012 \pm 0.010	0.000 \pm 0.000	0.000 \pm 0.000
<i>Dichanthelium</i> spp.	0.287 \pm 0.072	0.363 \pm 0.096	1.547 \pm 0.262
<i>Eriogonum tomentosum</i>	0.012 \pm 0.003	0.007 \pm 0.003	0.005 \pm 0.003
<i>Eupatorium compositifolium</i>	0.003 \pm 0.003	0.001 \pm 0.001	0.008 \pm 0.006
<i>Euphorbia discoidalis</i>	0.004 \pm 0.004	0.001 \pm 0.001	0.001 \pm 0.001
<i>Euphorbia floridana</i>	0.078 \pm 0.020	0.151 \pm 0.044	0.190 \pm 0.048
<i>Galactia floridana</i>	0.229 \pm 0.071	0.224 \pm 0.095	0.255 \pm 0.101
<i>Gaylussacia dumosa</i>	0.320 \pm 0.114	0.207 \pm 0.088	0.155 \pm 0.072
<i>Hypoxis juncea</i>	0.034 \pm 0.019	0.016 \pm 0.009	0.016 \pm 0.006
<i>Leptoloma cognatum</i>	0.000 \pm 0.000	0.000 \pm 0.000	0.007 \pm 0.004
<i>Liatris</i> spp.	0.030 \pm 0.014	0.022 \pm 0.012	0.102 \pm 0.039
<i>Licania michauxii</i>	0.684 \pm 0.259	0.463 \pm 0.204	0.550 \pm 0.194
<i>Lupinus diffusus</i>	0.004 \pm 0.003	0.005 \pm 0.005	0.019 \pm 0.004
<i>Opuntia humistrata</i>	0.000 \pm 0.000	0.001 \pm 0.001	0.001 \pm 0.001
<i>Panicum virgatum</i>	0.014 \pm 0.009	0.001 \pm 0.001	0.000 \pm 0.000
<i>Paspalum setaceum</i>	0.020 \pm 0.004	0.028 \pm 0.017	0.020 \pm 0.010
<i>Pinus clausa</i>	2.399 \pm 0.275	0.089 \pm 0.031	0.105 \pm 0.025
<i>Pinus palustris</i>	0.004 \pm 0.002	0.030 \pm 0.027	0.100 \pm 0.016
<i>Pityopsis aspera</i>	0.013 \pm 0.005	0.003 \pm 0.002	0.003 \pm 0.002
<i>Pityopsis graminifolia</i>	0.014 \pm 0.014	0.004 \pm 0.004	0.010 \pm 0.010
<i>Polygonella gracilis</i>	0.013 \pm 0.008	0.004 \pm 0.004	0.007 \pm 0.007
<i>Pteridium aquilinum</i>	0.007 \pm 0.003	0.013 \pm 0.005	0.059 \pm 0.044
<i>Quercus geminata</i>	1.356 \pm 0.652	1.712 \pm 0.753	2.284 \pm 0.974
<i>Rhynchosia cytisoides</i>	0.061 \pm 0.020	0.050 \pm 0.015	0.089 \pm 0.020
<i>Rhynchospora grayi</i>	0.057 \pm 0.012	0.008 \pm 0.004	0.034 \pm 0.016
<i>Schizachyrium scoparium</i>	0.139 \pm 0.041	0.051 \pm 0.020	0.064 \pm 0.020
<i>Schizachyrium tenerum</i>	0.068 \pm 0.018	0.017 \pm 0.008	0.021 \pm 0.008
<i>Schrankia microphylla</i>	0.008 \pm 0.005	0.005 \pm 0.004	0.009 \pm 0.005
<i>Scleria ciliata</i>	0.011 \pm 0.006	0.005 \pm 0.003	0.015 \pm 0.004

Table 4.1. Continued.

Species	Year		
	1994	1995	1996
<i>Serenoa repens</i>	0.025 ± 0.010	0.018 ± 0.007	0.023 ± 0.009
<i>Smilax auriculata</i>	0.829 ± 0.289	0.637 ± 0.168	0.809 ± 0.203
<i>Solidago odora</i>	0.014 ± 0.006	0.005 ± 0.004	0.011 ± 0.006
<i>Sorghastrum secundum</i>	0.001 ± 0.001	0.004 ± 0.002	0.003 ± 0.002
<i>Sporobolus junceus</i>	0.064 ± 0.008	0.016 ± 0.009	0.021 ± 0.010
<i>Stylisma patens</i>	0.060 ± 0.008	0.035 ± 0.009	0.048 ± 0.009
<i>Stylosanthes biflora</i>	0.000 ± 0.000	0.001 ± 0.001	0.001 ± 0.001
<i>Tephrosia chrysophylla</i>	0.005 ± 0.004	0.025 ± 0.013	0.035 ± 0.012
<i>Tephrosia mohrii</i>	0.064 ± 0.021	0.042 ± 0.019	0.082 ± 0.038
<i>Tradescantia hirsutiflora</i>	0.003 ± 0.002	0.003 ± 0.002	0.004 ± 0.002
<i>Tragia smallii</i>	0.013 ± 0.009	0.021 ± 0.018	0.022 ± 0.018
<i>Tragia urens</i>	0.034 ± 0.013	0.026 ± 0.009	0.038 ± 0.013
<i>Triplasis americana</i>	0.024 ± 0.009	0.004 ± 0.003	0.005 ± 0.003
<i>Vaccinium darrowii</i>	0.005 ± 0.004	0.004 ± 0.004	0.010 ± 0.007
<i>Yucca flaccida</i>	0.005 ± 0.005	0.005 ± 0.003	0.008 ± 0.004

SAND PINE REMOVAL

Table 4.2. Temporal vegetation changes since pre-treatment sampling in response to sand pine removal (1994-1996). Change in variable level include the change from pre-removal condition. Removal of sand pine was conducted from January 1995 to August 1995.

Variable	Increased	Decreased	Increasing after initial decline	No change
Plant species richness			X	
Florida spurge	X			
Low panic grasses	X			
Sand live oak	X			
Wiregrass	X			
Dwarf huckleberry		X		
Sand pine		X		
Broomsedge			X	
Catbrier			X	
Gopher apple			X	
Little bluestem			X	
Pineland hoary-pea			X	
Florida milk-pea				X

5. INITIAL EFFECTS OF HARDWOOD REDUCTION TECHNIQUES ON ARTHROPOD FAMILIES AND MORPHOSPECIES IN SANDHILLS AT EGLIN AIR FORCE BASE, FLORIDA

ABSTRACT

We compared the initial effects of three hardwood reduction techniques (growing season burning, herbicide [ULW[®] form of hexazinone] application, chainsaw felling/girdling) and no-treatment control on arthropod family and species and morphospecies densities in fire-suppressed sandhills at Eglin Air Force Base, Florida. In spring 1996, 9 out of 195 arthropod family densities significantly dependent on the restoration treatments: leaf beetles (Coleoptera: Chrysomelidae), dance flies (Diptera: Empididae), braconid wasps (Hymenoptera: Braconidae), clubionid spiders (Araneae: Clubionidae), psocids (Psocoptera: Psocidae), sminthurid springtails (Collembola: Sminthuridae), flatid planthoppers (Homoptera: Flatidae), grasshoppers (Orthoptera: Acrididae), and phlaeothripid thrips (Thysanoptera: Phlaeothripidae). Springtails, flatid planthoppers, grasshoppers, and thrips responded positively to burning, probably because of the improved forage value of the resprouting plants on these sites. Braconid wasps, dance flies, and grasshoppers also increased in felling/girdling plots. Clubionid spiders and psocid densities were higher in ULW[®] plots. ULW[®] application also caused a slight, but potentially significant increase in grasshopper densities compared to control plots. Leaf beetles only increased in control plots. Four out of 225 morpho/species responded significantly to treatment application. Dance fly #1 (Diptera: Empididae) and *Erythroneura* leafhoppers (Homoptera: Cicadellidae) achieved their highest densities in felling/girdling plots, whereas the sminthurid springtail *Sminthurus carolinensis* (Collembola: Sminthuridae) and the flatid planthopper *Metcalfa pruinosa* (Homoptera: Flatidae) were more abundant in burn plots.

We also investigated correlations between arthropod family biomass and density versus measures of ground cover plant composition and tree species density and basal area. We found that ground cover variables, plant species richness, and longleaf pine (*Pinus palustris*) regeneration were more often correlated with arthropod density and biomass than were any pine or hardwood tree variable before and after treatment application. Graminoid cover, forb cover, woody species cover, bare ground cover, and plant species richness were positive predictors of homopterans, hemipterans, ants, moths, and grasshoppers before and after treatment application. Tree density and basal area were infrequently correlated with arthropod density or biomass.

Overall, results indicate that growing season burning increased arthropod density and biomass more than that of other treatments. Because northern bobwhite quail (*Colinus virginianus*), wild turkey (*Meleagris gallopavo*), red-cockaded woodpeckers (*Picoides borealis*), and other wildlife feed heavily on arthropods, especially during the breeding season, we suggest that managers could burn to increase arthropod availability. Continued sampling and comparisons of these results to treatment effects on trees and plants will provide broad criteria for judging the cost and benefits of different restoration techniques.

INTRODUCTION

Restoring fire-suppressed sandhill communities often includes reducing hardwood structure and increasing herbaceous cover. Unnaturally high densities of hardwoods (e.g., turkey oak [*Quercus laevis*]) and invading sand pine (*Pinus clausa*) in the sandhills of Eglin Air Force Base (EAFB) and elsewhere have resulted from fire suppression and habitat fragmentation (Myers 1990, DoD-Air Force 1993). Degradation of this longleaf pine (*Pinus*

palustris) community, notable for its high species richness at small spatial scales (Walker and Peet 1983, Huston 1994, Provencher et al. 1997), also results in reduced plant richness. Most studies of restoration of degraded sandhills, however, are vegetation based and little has been published on arthropods in longleaf pine-dominated sandhills.

Much less is known about invertebrates than about any other taxonomic group in longleaf pine ecosystems (Folkerts et al. 1993, Hooper 1996). In longleaf pine ecosystems, as in most ecosystems, invertebrates, especially insects, account for >80% of the species richness and are key to nutrient dynamics and food chain relationships (Folkerts et al. 1993, James et al. 1997, Hanula and Franzreb 1998). Folkerts et al. (1993) proposed a minimum of 4,000-5,000 species of arthropods as a conservative estimate of species richness for xeric longleaf pine habitats. (Perhaps 90% of these species are also found in other habitats [Folkerts et al. 1993].)

The relative contributions of arthropods to longleaf pine ecological processes presumably differ from those of other North American vegetation types in two important respects (Folkerts et al. 1993). First, longleaf pine is more resistant to herbivore attacks compared to other pines, and few herbivore pests are considered longleaf pine specialists (Hodges et al. 1979). The copious resin production of longleaf pine is partly credited for this unusual resistance (Hodges et al. 1979). The natural resistance to herbivory, which confers additional longevity to an already long-lived tree, means that the stem surface is a temporally stable environment that could harbor predictable population densities of fire-resistant species (e.g., ants [Hymenoptera: Formicidae], spiders [Araneae], and wood roaches [Blattaria: Blattellidae] to name a few [Hanula and Franzreb 1995, 1998, Hooper 1996, James et al. 1997]) and, thus, serve as a dependable food reservoir for arthropod consumers (e.g., red-cockaded woodpeckers [*Picoides borealis*], brown-headed nuthatches [*Sitta pusilla*], pine warblers [*Dendroica pinus*], and lizards). Longleaf pines can also serve as a refuge from fire for arthropods living in the herbaceous layer, because a significant fraction of arthropods found on the bark and limbs of longleaf pines apparently originate from the ground level (James et al. 1997, Hanula and Franzreb 1998).

Second, chronic fires, which burn a large, but variable, proportion of the understory and litter, prevent the accumulation of litter and humus needed to support large populations of soil arthropods, except in microsites (Folkerts et al. 1993). This fire effect may be even stronger in xeric sandhills where organic matter is low. Consequently, soil arthropods may contribute little to the return of nutrients to the soil in well-burned savannas compared to temperate hardwood forests. Folkerts et al. (1993) suggested that the feces of herbivores and, presumably, their predators may be the most important contribution of arthropods to nutrient cycling in these grass-dominated systems. Similarly, Ritchie and Tilman (1993) detected significant effects of grasshoppers on concentrations of soil nitrogen in experimental field cages from Minnesota prairies. Grasshoppers (Orthoptera: Acrididae) presumably returned nitrogen to the soil through feces; in addition, grazing on little bluestem from poorer soils reduced its nitrogen intake, thus increasing available soil nitrogen. Microbial activity readily transforms feces into nutrients without the need of litter-degrading arthropods.

Although some arthropod taxa lists have been published for longleaf pine forests, very few studies report quantitative estimates of terrestrial arthropod densities (Folkerts et al. 1993, Hooper 1996, Hanula and Franzreb 1995, 1998). Provencher et al. (1996) collected 230 families of invertebrates with Malaise traps and a combined sweep net and D-Vac suction device quadrat sampling method in 30, 20-ha (50-acre) plots at Eglin Air Force Base (EAFB) during two seasons of sampling (fall 1994 and spring 1995) (Appendix B). This large number of families is a sizable fraction of the 574 terrestrial families occurring in North America (following the classification of Borror et al. [1989]). Furthermore, 13 of the 230 families are unlikely to be encountered by general collectors (Borror et al. 1989). Density estimates of herb-layer arthropods were obtained for many of these families. Numerically dominant groups were flies (Diptera), ants and wasps (Hymenoptera), aphids and hoppers (Homoptera), spiders (Araneae), grasshoppers, and springtails (Collembola).

Not surprisingly, quantitative studies of arthropod population responses to management activities, restoration techniques, or fire are rare for longleaf pine forests (e.g., Provencher et al. 1996, 1997). Studies from other systems are more common. Populations of specialist ground beetle (Coleoptera: Carabidae) species in Canada exhibited rates of responses to clear-cut logging varying from immediate disappearance to a gradual decline over 9 years (Niemelä et al. 1993). Similar results were found by Lenski (1982) for ground beetles in the southern Appalachians. Spider species assemblages on restored bauxite mines in Australia were still recovering 18 years after restoration; recovery of spiders was shown to depend predominantly on accumulation of litter and vegetative cover (Simmonds et al. 1994). McCoy and Kaiser (1990) detected a positive relation between fire frequency and colony density of southern harvester ants (*Pogonomyrmex badius*) in central Florida sandhills. Chronic fires open the midstory, and as a result, promote the dryer and sunnier conditions preferred by these ants. These authors also showed that the foraging area of southern harvester ants increased after a burn. They hypothesized that fire reduced resource availability for these ants, thus forcing them to forage in larger areas.

On the other hand, many herbivores and phytophagous insects quickly return to burned areas because of the rapid regeneration of palatable vegetation (Harris and Whitcomb 1974). Reed (1997) reviewed studies investigating fire effects on prairie arthropod communities. She found that fire modified arthropod communities compared to unburned sites and that communities changed with time since burning. Repeated burns will initiate a successional cycle of plant and arthropod species composition and abundance. Prairies with fires initiated in different years and different seasons should achieve the highest species richness (Reed 1997). In a 30-year study in oak savannas, Siemann et al. (1997) showed that frequency of burning did not cause any significant changes in overall arthropod abundance, species richness, or diversity.

In this paper, we studied two aspects of arthropod ecology in restored sandhills. First, we experimentally compared the initial effects of three hardwood reduction techniques (growing season burning, herbicide [ULW[®] form of hexazinone] application, chainsaw felling/girdling) and no-treatment control on arthropod family and morpho/species densities in fire-suppressed sandhills at Eglin Air Force Base, Florida. Treated sandhills were also contrasted to frequently-burned longleaf pine-dominated sandhills, which were not part of the experimental design. Results will be limited to the first two years of the study. Second, we investigated correlations between arthropod family biomass and density versus measures of ground cover plant composition and tree species density and basal area.

Hypotheses of Treatment Effects. The herbicide ULW[®] (E. I. DuPont de Nemours and Co., Wilmington, DE) would decrease midstory tree cover and the cover of woody understory species (primarily oaks [*Quercus* spp.]) and herbaceous species it is known to kill (e.g., broomsedge [*Andropogon virginicus*], dog fennel [*Eupatorium compositifolium*], and goldenrods [*Solidago* spp.]). Hardwood leaf litter should greatly increase due to the successive leaf falls caused by the herbicide. Therefore, we predicted that invertebrate species that prefer open, sunny habitats (e.g., grasshoppers and pollinators) and/or feed on or live in decomposing hardwood leaf litter (e.g., springtails, beetles, and some spiders) would increase in ULW[®] plots.

Prescribed growing season burning was expected to enhance densities of invertebrates that feed on soft-tissued plants, because resprouting plant tissue contains higher levels of nitrogen relative to carbon than older tissue (Christensen 1993), thus providing more palatable forage. Predators and parasites of these herbivores (e.g., other invertebrates and birds) should positively respond to greater invertebrate availability.

Except for the very predictable increase in woody litter and decrease in canopy cover from chainsaw felling, we did not expect any initial vegetation changes from these plots compared to controls during the first year. Invertebrates that seek open habitats and slash were predicted to

rapidly respond to felling/girdling operations. Also, wood-boring insects attracted to felled and girdled oaks were expected to increase in Malaise traps, and to a lesser degree, in the herb-layer. Over time, we expected that herbivorous insects would increase as herbaceous plant populations responded to increased sunlight and leaching of nutrients from decaying slash (Boyer and Miller 1994).

Hypotheses for Correlations Between Arthropods and Tree and Plant Cover Variables.

Recent studies (James et al. 1997, Hanula and Franzreb 1998) have shown that the federally endangered red-cockaded woodpecker feeds on invertebrates that may disperse from the groundcover to the bark of longleaf pines. Hanula and Franzreb (1998) showed that red-cockaded woodpecker prey dispersed from the ground level and that the contribution of ground cover arthropods decreased from 70% to 0% from the base to the crown of the tree. Therefore, we investigated the relationship between herb-layer arthropods and measures of red-cockaded woodpecker reproductive success.

Hardesty, Gault, and Percival (1997) found that the number of red-cockaded woodpecker eggs, number of nestlings, and number of fledglings at EAFB increased with forb cover. James et al. (1997) also found that red-cockaded woodpecker variables were highly significantly correlated to ground cover composition (positively with wiregrass [*Aristida stricta*] and negatively with gallberries [*Ilex glabra* and *Ilex coriacea*]) and the area of forest with longleaf pine regeneration in the Apalachicola National Forest, Florida. Presumably, forb cover increased with the openness of the stand due to increased sunlight and fire, and this promoted invertebrate activity and density.

Hardwood species abundance has also influenced red-cockaded woodpeckers at EAFB. The number of eggs decreased with hardwood height and hardwood mean diameter at breast height (DBH), and the number of nestlings decreased with hardwood height and the percent cover of hardwood stems (Hardesty, Gault, and Percival, 1997). The basal area of hardwoods is highly correlated to their height, DBH, and density (Provencher et al. 1996, 1997, see also Chapter 3). Again, we hypothesized that invertebrate activity and density increase with stand openness and forb cover, which occurs when hardwood density and basal area decrease.

Finally, longleaf pine stem density (>25 cm [10 in] DBH) is negatively correlated with the number of red-cockaded woodpecker eggs, which decreased with the density of large (>25 cm or 10 in) longleaf pines. The number of nestlings decreased with the basal areas of live, of total (live and dead) longleaf pines, and of longleaf pines greater than 25 cm (10 in). The number of fledglings decreased with the basal areas of live and total longleaf pines, and with the density of longleaf pines >25 cm (10 in) (Hardesty, Gault, and Percival 1997). These latter relationships are more difficult to connect to invertebrate density, because the highest densities and diversity of invertebrates have been found in sites with the highest basal areas and densities of large pines (Provencher et al. 1996, 1997). Also, James et al. (1997) could not find significant relationships between bird variables and size or density of longleaf pines. The only significant correlation among red-cockaded woodpecker variables and longleaf pine was positive and with the extent of regeneration. These results would be opposite to those reported by Hardesty, Gault, and Percival (1997) if the density of large longleaf pines is positively correlated to seed and seedling production. James et al. (1997) hypothesized that the number of eggs depends on female red-cockaded woodpecker nutrition (more specifically calcium in invertebrates), which could be influenced by the nutrient content of ground cover plant material and, ultimately, by fire regimes. We hypothesize that there is a non-negative relationship between invertebrate density and the density or basal area of large longleaf pines.

In summary, we tested the hypothesis that arthropod density or biomass increased with vegetation ground cover measures, with plant species richness, and with the density of longleaf pine regeneration, but decreased with hardwood basal area with the density of large longleaf pines (>25 cm), and with longleaf pine basal area. More generally, these relationships, except perhaps the latter, would apply to other sandhill birds such as northern bobwhite quail (*Colinus*

virginianus), wild turkey (*Meleagris gallopavo*), and Bachman's sparrow (*Aimophila aestivalis*) (Engstrom 1993).

SITE DESCRIPTION

EAFB occupies the southern portions of Walton, Okaloosa, and Santa Rosa Counties in the western Florida Panhandle (Fig. 5.1). EAFB is bordered by the Yellow River and Alaqua Creek to the north and east and by the Gulf of Mexico and Choctawhatchee Bay to the south and east. Forestry and military activities have resulted in significant soil alteration across EAFB. Earth mining, roads, clearcuts, selective timber harvest, stumping, fire breaks, tank activity, and other activities now create a mosaic of disturbances in both fire-suppressed and frequently-burned longleaf pine stands at EAFB. Sandhill sites selected for this study varied in degree of past fire frequency, soil alteration, and groundcover dominants.

The climate is temperate with mild winters and hot, humid summers. Winters tend to be somewhat milder near the coast compared to the inland regions (Chen and Gerber 1990). The mean annual temperature is 18.3° C, with approximately 275 freeze-free days per year. Thunderstorms and lightning strikes are frequent during the summer months. Mean annual precipitation is 158 cm per year (DoD-Air Force 1995). Monthly precipitation levels peak slightly during late spring and early summer months and decrease during the winter months. Snow accumulation is rare. Tropical storms are frequent along the Gulf Coast of Florida and neighboring states. Between 1871 and 1985, 115 tropical storms and hurricanes made landfall within 110 km of EAFB (NOAA 1994).

The terrain is level to gently rolling with occasional areas of steeply inclined terrain. Elevation ranges from 0-100 m above sea levels and the landscape generally slopes to the southwest toward the Gulf of Mexico. The Citronelle Formation (Pleistocene) is the dominant parent material for the surficial sediments (Overing et al. 1995). It consists of sand (>90%), clay, and gravel with occasional limonite beds, lenses, and pavements (Overing et al. 1995). Throughout most EAFB sandhills, the Lakeland soil series is the common upper soil horizon. This series is a thermic, coated Typic Quartzipsamments, characterized as a rapidly permeable and strongly acidic sandy soil with nearly level to steep slopes.

With a historically high fire frequency (approximately 1-10 years), the longleaf pine sandhill community is characterized by a nearly pure overstory of longleaf pine, a sparse midstory of hardwoods (oaks and other species), and a diverse groundcover dominated by perennial graminoids and forbs (Myers 1990). Following extended periods of fire suppression, a dense midstory of oaks and other hardwood tree species develops, and groundcover of graminoids and forbs significantly decreases (White et al. 1991, Robbins and Myers 1992). Fire suppression also results in increased importance of medium statured shrubs (e.g., blueberries [*Vaccinium* spp.]) and woody vines (e.g., catbrier [*Smilax* spp.]) in the midstory.

The Panhandle arthropod fauna is not well known. EAFB exhibits an extraordinary number of endemic and rare plant species (Kindell et al. 1997). It seems likely that EAFB will support a host of endemic and rare invertebrate species, as well. A number of rare invertebrate species are known only from counties in northwest Florida (Deyrup and Franz 1994), and many of these may occur on EAFB. A host of uncommonly collected species have turned up during project sampling (Provencher et al. 1997), including: *Embolemus nearcticus* (Hymenoptera: Embolemidae) (Borror et al. 1989); *Rhopalosoma nearcticum* (Hymenoptera: Rhopalosomatidae) (Borror et al. 1989); *Plectoptera picta* (Blattaria: Blattellidae) (Helfer 1987); *Mycetobia divergens* (Diptera: Anisopodidae) (Borror et al. 1989); a new species of *Selonodon* (Coleoptera: Cebrionidae) (Galley, *in press*); *Polylamina pubescens* (Coleoptera: Scarabaeidae) (Deyrup and Franz 1994); *Periscelis* sp. (Diptera: Periscelididae) (Borror et al. 1989); *Lomamyia* sp. (Neuroptera: Berothidae) (Borror et al. 1989); and *Micremphis* sp. (Diptera:

Empididae) (Steyskal and Knutson 1981). New county records from EAFB are expanding the ranges of species, including: *Ceratobarys eulophus* (Diptera: Chloropidae) (G. Steck, Division of Plant Industry, *pers. comm.*); *Ischyryus dunedinensis* (Coleoptera: Erotylidae) (Skelley and Goodrich 1989); *Milichiella lacteipennis* (Diptera: Milichiidae) (G. Steck, *pers. comm.*); *Rivellia metallica* (Diptera: Platystomatidae) (G. Steck, *pers. comm.*); *Sminthurus floridanus* (Collembola: Sminthuridae) (Snider 1982); and *Acontistoptera melanderi* (Diptera: Phoridae) (B. Brown, Natural History Museum of Los Angeles County, *pers. comm.*). Many of these records were previously unknown for north Florida.

METHODS

Experimental Design

Restoration Blocks. A total of 24, 200-acre (80.84-ha) plots were established in six blocks of four fire-suppressed hardwood-longleaf pine sandhill plots across an west/east transect of EAFB (Fig. 5.1: B-7, Wolf Creek, Metts Creek, Malone Creek, Exline Creek, C-72). Within each of the six blocks created, site characteristics were considered sufficiently homogeneous among the member plots for our study to conform to a split-plot, randomized complete block design (Steel and Torrie 1980). In keeping with this design, each plot within an experimental block was randomly assigned without replacement to either control designation (no treatment), or to one of three following restoration treatments applied during the spring and early summer of 1995: growing season burn in May and June; herbicide (ULW[®], the granular form of hexazinone with 75% active ingredient applied at a rate of 2.44 kg/ha [2 lb/acre]); and oak and sand pine felling/girdling by chainsaw (slash not removed). All plots were selected if they were located in areas larger than 81 ha (200 acres) that contained a high density of relatively large diameter hardwood trees, had been fire-suppressed for several decades, and were adjacent to three other such sites. Plots had a relatively sparse herbaceous understory and a thick litter of hardwood leaves interspersed with bare ground. The occurrence of recent small wildfires (<0.5 ha [1 acre]) or small creeks within a plot did not disqualify it from consideration.

In each 81-ha (200-acre) plot, all subplots and sampling stations were located in the 20-ha (50-acre) corner farthest from the neighboring plots of the block to alleviate the potential for recording organisms (i.e., birds, insects) that can travel across adjacent plot boundaries (Fig. 5.3). We borrowed from split-plot terminology to label our nested sampling units: each 81-ha (200-acre) plot contains 32 10 × 40-m subplots (Figs. 5.2-5.3); any sampling unit within a subplot is referred to as a sub-subplot. The 32 subplots within each plot were arranged in groups of four to test the effect of distance between subplots on the mean and variability of potentially patchy variables, such as species or characteristics that might be clumped in distribution at one or both scales (the split-plot component of the experimental design) (Fig. 5.3). The two distance treatments were 10 and 50 m between centers of two consecutive subplots. Variables describing soils, herbaceous plants, trees, invertebrates, birds, and mammal activity were quantified on restoration plots. (See below for description of arthropod variables only.)

Reference Blocks. A total of six 81-ha (200-acre) frequently-burned longleaf pine-dominated sandhill plots were established (Fig. 5.1: A-77; A-78; and B-75) to provide objective goals for the restoration of fire-suppressed plots. Reference plots were not part of the restoration experimental design described above, but are a critical research component, because they provide a benchmark for measurement of the success and efficacy of the restoration treatments applied.

Reference plots were chosen on the basis of the following criteria: a square area larger than 81 ha (200 acres); uneven age distribution of longleaf pines; presence of old-growth longleaf pines; abundance of fine fuels interspersed with bare ground; openness of the forest; presence

of active red-cockaded woodpecker clusters; and a history of frequent growing season fires. Because of the difficulty in satisfying these requirements, we located only three blocks, each consisting of two 81-ha (200-acre) plots.

Selected reference blocks A-77 and B-75 were designated by the association "*Pinus palustris/Quercus laevis/Schizachyrium scoparium-Rhynchosia cytisoides* Woodland" (The Nature Conservancy 1997a), for which EAFB is the type class. However, reference block A-78 conformed to the type "*Pinus palustris/Quercus laevis/Aristida beyrichiana-Croton argyranthemus* Woodland" (The Nature Conservancy 1997a, Rodgers and Provencher, *in press*). Peet and Allard (1993) also designated these sites as "Southern Xeric Longleaf Pine Woodlands." The characteristic plants of this group include longleaf pine, turkey oak, blue-jack oak (*Quercus incana*), pineywoods dropseed (*Sporobolus junceus*), and gopher apple (*Licania michauxii*). Other common species reported by these authors are wiregrass, persimmon (*Diospyros virginiana*), saw palmetto (*Serenoa repens*), tread softly (*Cnidioscolus stimulosus*), wild buckwheat (*Eriogonum tomentosum*), grass-leaf golden aster (*Pityopsis graminifolia*), weak-leaf yucca (*Yucca flaccida*), and silver croton (*Croton argyranthemus*).

Each reference plot contained the same subplot sampling design as the experimental plots, but the sampling site was located in the plot centers (Fig. 5.3). This arrangement reflected our desire to avoid potential edge effects on these sites. Variables describing soils (Chapter 2), herbaceous plants (Chapter 3), trees (Chapter 3), invertebrates (this chapter), birds (Chapter 6), and mammal activity were quantified on reference blocks.

Arthropod Sampling

Herb-layer invertebrate densities were estimated for each 20-ha (50-acre) sampling area within a plot by family, superfamily, or order in restoration and reference blocks. In some cases, specimens were identified to species or morphospecies. Morphospecies are taxa that can be readily separated by non-specialists using obvious morphological differences (Oliver and Beattie 1996). In order to successfully collect invertebrates of various sizes and mobilities, individuals were first collected using a sweep net, immediately followed by a D-Vac insect vacuum method, which we modified. In 1994, individuals were collected from herb-strata vegetation (<1.4 m) within the same four 0.5 × 2-m areas used for understory vegetation sampling (Fig. 5.3). Because we suspected that the noise and motion of our suction device and sweep net were flushing some invertebrates from adjacent sub-subplots at the 10 m sampling distance, we changed the location and shape of invertebrate sampling sub-subplots to one 0.5 × 8 m rectangle situated in the center of the subplot beginning in fall 1995 (Fig. 5.3). Moreover, the second method minimized escapes by invertebrates since we opened the sweep net once instead of four times. Species presence of invertebrate families was also sampled on each 81-ha (200-acre) plot using a Malaise trap placed in the center of the 50-acre sampling area (Fig. 5.3). The trap was left in place for 2 days. Species from sweep net/D-Vac and Malaise trap samples were manually sorted and preserved in 70% ethanol.

In order to relate numbers of invertebrates to their biomass, average body lengths of members of invertebrate families or orders encountered were estimated from specimens obtained from sweep net/D-Vac. Invertebrate biomass is an alternative measure of invertebrate availability that may compensate for the well-documented fact that a few, large-bodied invertebrates (e.g., grasshoppers) account for a large amount of food for other animals, and that small invertebrates may be abundant, but not amount to much biomass (Peters 1983). We measured at least 30 individuals/taxon when specimen abundance permitted; otherwise, we measured the maximum number available (additional specimens were captured by Malaise traps situated in the center of each 81-ha [200-acre] plot). Length measurements were taken from the head to the end of the abdomen, not including appendages. We measured specimens using either a micrometer or ruler as appropriate. Biomass was estimated from body length (Provencher et al. 1997).

We selected 6 orders and 33 families of insects and spiders to target for species and morphospecies analysis (hereafter referred to as morpho/species). These orders and families contained morpho/species that both occurred in high density and remained identifiable after D-Vac collection. We enlisted the assistance of taxonomic specialists where possible to perform species identifications and established a reference collection of 225 authoritatively identified adult arthropod morpho/species (Appendix C). This growing collection permitted us to determine the density of some morpho/species. However, most immature specimens of these and other species cannot be easily identified below the family level. For example, few grasshoppers, which show significant treatment effects at the family level (see above), could be identified to the species level, because most individuals that we captured in the spring were early instar nymphs. An unfortunate and inevitable consequence of focusing on morpho/species compared to families was that densities decreased (and the frequency of zero densities increased) with increasing taxonomic nesting. As a result, it becomes statistically more difficult to detect significant treatment effects. Because the majority of insect species (to date, approximately 1 million described species [Wheeler 1990]) do not have a common name approved by the Entomological Society of America, common species names are not given below.

Data Collection Timeline. In the restoration and reference plots, response variables and dates of collection for various invertebrate sampling methods (some not described here, but see Provencher et al. 1997) are outlined as follows:

Response variable	Season		Beginning date	Ending date
Herb strata	Fall 1994:	Pre-treatment	12 October 1994	5 December 1994
Species presence	Fall 1994:	Pre-treatment	28 September 1994	13 January 1995
Herb strata & soil/litter	Spring 1995:	Pre-treatment	1 April 1995	15 June 1995
Herb strata & species presence	Fall 1995:	Post-treatment	15 July 1995	3 October 1995
Herb strata & soil/litter	Spring 1996:	Post-treatment	1 April 1996	15 June 1996
Herb strata & species presence	Fall 1996:	Post-treatment	15 July 1996	10 October 1996

Statistical Analyses

We graphed the pre- and post-treatment average whole-plot medians, 25 and 75% quartiles, and minimum and maximum values of the statistically significant variables. (Fifty percent of values are smaller or greater than the median. The 25 and 75% quartiles contain the central 50% of the data values; therefore, data from three of six replicates closest to the median are contained within the 25 and 50% quartiles.) We chose to graph the median and 25 and 75% quartiles because they show the actual distribution of the data; however, the statistical tests described below and reported on the figures are based on means and variances. When a variable was not significantly affected by restoration treatments, we tabulated its mean and standard error per treatment and reference plots.

ANCOVA. We tested restoration treatment effects with a randomized complete block analysis of covariance (ANCOVA) (Steel and Torrie 1980) for selected variables in restoration plots. The subplot level (sampling distance) of the split-plot design was not tested. We tested the effect of pre-treatment data on post-treatment data as a covariate within the tests for restoration treatments in ANCOVAs for restoration plots. In ANCOVAs, pre-treatment data were used to adjust post-treatment averages to account for differences among treatments that existed prior to treatment application. The adjusted averages were the values used in the figures. Adjusting means involved using the estimated regression slope obtained from ANCOVA to calculate the expected dependent variable when all independent variables we set to a common average and regression slope (Steel and Torrie 1980). When pre-treatment data are available and meet the assumptions of ANCOVA, this latter method is more precise and powerful than analysis of variance (ANOVA) of response variables adjusted to reflect the

contribution of pre-treatment data or simply unadjusted variables (Steel and Torrie 1980, Sokal and Rohlf 1981, Streng et al. 1993).

We performed three independent contrasts to compare treatment means. Because it is only possible to perform a maximum number of contrasts that is equal to the degrees of freedom for restoration treatments (3 df) (Sokal and Rohlf 1981), which is less than the number of possible comparisons, we strategically chose to compare the following treatments: control versus burn, burn versus ULW®, and burn versus felling/girdling. In the first contrast, we tested whether doing nothing or maintaining fire suppression (control) performed as well as burning. Burning is the management default at EAFB, because it is the least expensive management tool available to managers and because chronic fires would characterize the maintenance condition of sandhills. Both felling/girdling and ULW® are more expensive management techniques in comparison to burning, and their efficacy should be compared to burning, but not to fire suppression.

We performed ANCOVAs on arthropod family densities and arthropod morpho/species densities using a computer randomization test (Edgington 1987). Two reasons justified the extra effort of programming the tests. First, we had so many families and morpho/species (>100) to consider that it became cumbersome and very time-consuming to separately test each variable with commercial software. Thus, we wrote a computer program that processed all variables at the same time. Secondly, many common invertebrate taxa exhibited such low densities that their frequency distributions approached binary distributions, which parametric statistics cannot handle (Edgington 1987). The randomization procedure is distribution free, but still depends on homogeneous variances among treatments. Briefly, the purpose of the computer test was to create a random distribution for a chosen statistic (e.g., variance of treatment effect) representing the original data through random permutations among treatments (i.e., the null hypothesis was that the observations can belong to any treatment) and, then, to determine if the observed statistic from the original unpermuted data was greater than or equal to 95% of the random values (i.e., if it is in the 5% tail of the distribution). If the original statistic was in the 5% tail of the distribution, the null hypothesis of no difference among restoration treatments was rejected with a significance probability that was equal to 1 - (relative rank of the original statistic in the distribution) (Edgington 1987). The three independent contrasts were performed with the same set of permutations and methods, but we used the "t" statistic with standard errors for two adjusted means calculated from ANCOVA (Steel and Torrie 1980) to compare means. We permuted the original data 10,000 times to create a random distribution for each variable. The effect of pre-treatment data on post-treatment values (covariate effect) was determined directly from the F-ratio calculated with the original data, and, thus, not the result of permutations. (A new randomization procedure would be required to test the covariate effect.) The significance probability for the covariate effect was approximately determined from a table. We partitioned sum of squares following the ANCOVA formulas in Steel and Torrie (1980) and Cochran and Cox (1957).

Most of the reported variables needed transformation, because they displayed non-normal distributions and heterogeneous variances, which are violations of parametric and, in the case of heterogeneous variances, distribution-free statistics. All invertebrate counts were transformed as \sqrt{X} (Sokal and Rohlf 1981), and logarithmic transformations ($\ln[X+1]$) were applied to biomass.

We did not test the significance of the block effect, which refers to the source of variation caused by the spatial difference among blocks, because it is impossible to mathematically test such an effect in block designs for which the treatment is an applied, repeated, and controlled (i.e., fixed) manipulation (Cochran and Cox 1957; Steel and Torrie 1980). The block*restoration treatment interaction was the error term (i.e., denominator in the F statistic) needed to test the effect of the restoration treatment. For simplicity and ease of reading, we

have termed the tests of restoration treatment in the statistical tables (Tables 5.1 and 5.3) as "restoration".

Correlations. We examine correlations between arthropod order density or biomass (potential wildlife prey) and several measures of plant ground cover: longleaf pine juveniles (<1.4 m high and not from the 1996 seed crop), longleaf pine seedlings from the 1996 seed crop, plant species richness, longleaf pine density (trees >25 cm DBH) and basal areas and hardwood species basal areas. These vegetation variables are presented in Chapter 3.

RESULTS

Arthropod Families. Densities of 9 out of 195 arthropod families (Appendix B) significantly ($P < 0.05$) responded to restoration treatments (Table 5.1): leaf beetles (Coleoptera: Chrysomelidae); dance flies (Diptera: Empididae); braconid wasps (Hymenoptera: Braconidae); clubionid spiders (Araneae: Clubionidae); psocids (Psocoptera: Psocidae); sminthurid springtails (Collembola: Sminthuridae); flatid planthoppers (Homoptera: Flatidae); grasshoppers (Orthoptera: Acrididae), and phlaeothripid thrips (Thysanoptera: Phlaeothripidae). In addition to these nine families, the following six were marginally significant ($P > 0.05$ and $P < 0.1$; Table 5.1): ladybeetles (Coleoptera: Coccinellidae); tumbling flower beetles (Coleoptera: Mordellidae); hump-backed flies (Diptera: Phoridae); horse and deer flies (Diptera: Tabanidae); acanaloniid planthoppers (Homoptera: Acanaloniidae); and issid planthoppers (Homoptera: Issidae). The data for these marginally significant families are presented in Table 5.2.

Only adjusted median leaf beetle densities were significantly higher in control plots than in other treatments ($P < 0.0559$; Table 5.1; Fig. 5.4). Average leaf beetle density doubled from 1995 to 1996 (Table 5.2). Average density also doubled in burn plots. Because this family showed borderline significant treatment effects, we could not perform contrasts.

The adjusted median densities of two families were only significantly higher in felling/girdling plots: dance flies ($P < 0.0000$; Table 5.1; Fig. 5.4) and braconid wasps ($P < 0.0000$; Table 5.1; Fig. 5.4). Dance flies were 8 times more abundant than the next highest median density from burn plots. Adjusted median braconid wasp density in felling/girdling plots was twice as high as those of other treatments.

The adjusted median densities of two families were significantly higher in ULW[®] plots: clubionid spiders and psocids (Fig. 5.4). Adjusted median clubionid spider densities were not significantly different between control and burn plots ($P < 0.1795$; Table 5.1), and between burn and felling/girdling plots ($P < 0.8205$; Table 5.1). Adjusted median clubionid spider density of 0.08/4 m² in ULW[®] plots was at least twice that observed in the burn plots, which was the next highest, and was significantly different ($P < 0.0000$; Table 5.1). Adjusted median psocid density was at least 2 times higher in ULW[®] plots than other treatments in 1996 ($P < 0.0000$; Table 5.1), which was also a large increase compared to nearly null pre-treatment densities (Table 5.2).

Four families showed significantly higher adjusted median densities in the burn plots (Fig. 5.5). Sminthurid springtails (hereafter termed springtails) were 4.5 times more abundant in burn plots than in felling/girdling plots, which was the next highest median density ($P < 0.0000$; Table 5.1). Adjusted median density in burn plots was significantly greater than in control plots ($P < 0.0000$; Table 5.1). Compared to pre-treatment levels, median springtail densities increased >10 times in burn plots and 6 times in felling/girdling plots, but decreased more than 2-fold in control and ULW[®] plots (Table 5.2). Adjusted median flatid planthopper densities were significantly higher in burn plots than in control plots ($P < 0.0000$) and than in felling/girdling ($P < 0.0000$) and ULW[®] plots ($P < 0.0229$; Table 5.1). Adjusted median grasshoppers densities were significantly more abundant in burn plots (1.4/4 m²) than in other plots ($P < 0.0000$ for control; $P < 0.0001$ for ULW[®]; $P < 0.0000$ for felling/girdling; Table

5.1). Although not tested by contrasts, we suspect that grasshopper densities in felling/girdling plots, and, perhaps, in ULW[®] plots, were significantly greater than in control plots (Fig. 5.5). Based on adjusted medians, more than twice as many grasshoppers were found in burn than in control plots (Fig. 5.5). Because treatment effect for thrips densities were borderline significant ($P < 0.0548$; Table 5.1), no contrasts were performed. All restoration treatments resulted in greater adjusted medians compared to control plots (Fig. 5.5). Burn plots showed the highest adjusted median, but it was doubtful that significant differences existed among restoration treatments.

Arthropod Morpho/Species. A pattern that readily emerged from analysis was the domination within some families by one or two morpho/species that were collected in high numbers, while other morpho/species were collected infrequently or perhaps seen only one time. Such dominant morpho/species included the ants *Crematogaster ashmeadi*, *Forelius pruinosa*, and *Monomorium viride* (Hymenoptera: Formicidae); the planthoppers *Metcalfa pruinosa* (Homoptera: Flatidae) and *Hysteropteris punctatus* (Homoptera: Issidae); the flies *Holopogon* sp. #1 (Diptera: Asilidae), dance fly #1 (Diptera: Empididae: undetermined), and *Melanomyza* sp. (Diptera: Lauxaniidae); the springtail *Sminthurus carolinensis* (Collembola: Sminthuridae); and the beetle *Attalus* sp. #2 (Coleoptera: Melyridae).

Four out of 225 morpho/species densities significantly ($P < 0.05$) responded to restoration treatments (Table 5.3): dance fly #1 (Diptera: Empididae: undetermined); *Sminthurus carolinensis* (Collembola: Sminthuridae); *Erythroneura* spp. (Homoptera: Cicadellidae: undetermined); and *Metcalfa pruinosa* (Homoptera: Flatidae).

Dance fly #1 ($P < 0.0094$; Table 5.3; Fig. 5.6) achieved significantly higher adjusted median densities in felling/girdling than in burn plots ($P < 0.00001$; Table 5.3), which were not significantly different from control ($P < 0.1009$) and ULW[®] plots ($P < 0.2339$). Patterns for *Erythroneura* spp. closely matched those of dance fly #1, with the exception that adjusted median density was significantly less in control plots than in burn plots ($P < 0.0046$; Table 5.3).

Sminthurus carolinensis ($P < 0.0018$) and *Metcalfa pruinosa* ($P < 0.0258$) showed their greatest densities in burn plots (Table 5.3; Fig. 5.6). The distribution of densities among plots for *Sminthurus carolinensis* (Fig. 5.14) was identical to that of its family (Fig. 5.5), because this species accounts for 98.8% of individuals collected by sweep net/D-Vac. In the case of *Metcalfa pruinosa*, adjusted median density was significantly greater in burn plots than in control plots ($P < 0.0002$; Table 5.3). Median densities in ULW[®] and felling/girdling plots did not appear significantly different from that of control plots (untested contrasts) because median densities from these two former treatments were significantly smaller than that of burn plots ($P < 0.0050$ for ULW[®]; $P < 0.00001$ for felling/girdling; Table 5.3).

At least five insect morpho/species sampled are regularly seen in reference plots but rarely or never collected in fire-suppressed treatment plots. These include the flies *Rivellia metallica* (Diptera: Platystomatidae), *Hippelates* sp. (Diptera: Chloropidae), and *Ceratobarys eulophus* (Diptera: Chloropidae); the beetle *Trigonorhinus rotundatus* (Coleoptera: Anthribidae); and the rare springtail *Sminthurus floridanus* (Collembola: Sminthuridae). Very little has been published on the life history of any of these species. It is suspected that *T. rotundatus* feeds on smut-infested bluestem (*Andropogon*) (B. D. Valentine, Ohio State University, *pers. comm.*), so it will likely occur wherever these grasses are in high density. The discovery of the unusual springtail *S. floridanus* at block A-78 is exciting, because this springtail has been collected only once since it was described in 1893 (Snider 1982). The flies *R. metallica* and *Hippelates* sp. are mainly seen in reference plots and are occasionally taken in treatment plots, especially in those that have been burned.

Correlations Between Arthropods and Plant Variables. All correlations described here were significant ($P < 0.05$) and are presented in parentheses. Forb, woody species, and bare ground cover were positively correlated to homopteran biomass during the pre-treatment spring

1995 (respectively, $r = 0.56$, 0.37 , and 0.57) (Table 5.5a-b). Woody understory species also positively correlated with ant density ($r = 0.44$) and biomass ($r = 0.44$). Graminoid cover was only correlated to thrips ($r = 0.38$).

During the fall 1995, forb cover was only and negatively correlated to fly density ($r = -0.41$) and biomass ($r = -0.39$). Bare ground positively correlated with homopteran density ($r = 0.43$) and biomass ($r = 0.43$) and orthopteran density ($r = 0.47$) and biomass ($r = 0.49$). Graminoid cover positively correlated to homopteran density ($r = 0.57$) and biomass ($r = 0.40$). In addition, graminoid cover, wiregrass and pineywoods dropseed cover, and woody species cover were correlated to hemipteran (Hemiptera) density (respectively, $r = 0.42$, 0.65 , and 0.43). Wiregrass and pineywoods dropseed cover was positively correlated to spider density ($r = 0.39$), but not biomass. Woody species cover was also positively correlated to moth (Lepidoptera) density ($r = 0.68$).

The densities of longleaf pine juveniles (<1.4 m high) that were not seedlings from the 1996 seed crop did not correlate to any arthropod density or biomass in any year. The density of longleaf pine seedlings from the 1996 bumper crop were negatively correlated to fly biomass in 1996 ($r = -0.37$) and beetle density and biomass in 1996 ($r = -0.37$, $r = -0.36$).

There were no correlations between fall 1994 plant species richness and arthropod density or biomass of spring 1995. However, the number of plant species from the first (fall 1995) and second (fall 1996) years post treatment were positively correlated to the following spring 1996 arthropods: hemipteran density ($r = 0.66$ for 1995 and $r = 0.50$ for 1996) and biomass ($r = 0.53$ for 1995 and $r = 0.41$ for 1996); homopteran density ($r = 0.57$ for 1995 and $r = 0.38$ for 1996) and biomass ($r = 0.42$ for 1995 only); and moth density ($r = 0.48$ for 1995 and $r = 0.42$ for 1996).

Turkey oak was not significantly correlated to any arthropod order in any year. Bluejack oak (*Quercus incana*) was negatively correlated to hemipteran density ($r = -0.39$), homopteran density ($r = -0.42$), and thrips density ($r = -0.36$) during the pre-treatment year. Sand live oak (*Quercus geminata*) positively correlated with fly density ($r = 0.41$) and biomass ($r = 0.49$) and hemipteran biomass ($r = 0.48$). Sand post oak (*Quercus margaretta*) was only positively correlated to fly biomass ($r = 0.39$). Persimmon positively correlated to ant density ($r = 0.38$) and biomass ($r = 0.38$).

One year post-treatment, yaupon (*Ilex vomitoria*) positively correlated with fly biomass ($r = 0.41$). Sand live oak positively correlated with orthopteran biomass ($r = 0.37$) and thrips density ($r = 0.53$) and biomass ($r = 0.50$). Sand post oak was positively correlated to orthopteran density ($r = 0.61$) and biomass ($r = 0.63$).

The density of longleaf pines with DBH >25 cm (10 in) did not correlate to any arthropod order density or biomass in 1995 and 1996. After relaxing the significance probability threshold to $P < 0.1$, (not reported in Tables) only beetle density was correlated to large longleaf pine densities in 1996 ($r = -0.30$). On the other hand, the basal area of longleaf pine was only positively correlated to moth density (Lepidoptera) in 1996 ($r = 0.37$).

DISCUSSION

Tests of Treatment Predictions. Table 5.6 summarizes the results of initial post-treatment effects on densities of arthropod families and morpho/species that responded significantly to treatments. We predicted that growing season burning would enhance herbivore densities because of the greater availability of palatable resprouting forage. We observed significant increases in the densities of springtails, flatid planthoppers, grasshoppers, and thrips (Figs. 5.4-5.6) (other herbivorous morpho/species are dominant subsets of the above families), which are all herbivores.

The springtail *Sminthurus carolinensis* was first described in 1981 from the Savannah River Plant in Aiken, SC. Snider (1981) reports sweeping this species from open, dry areas with sparse grass mixed with *Allium vineale*. No other life history information is available on this springtail species.

The flatid planthopper *Metcalfa pruinosa* is found on a wide variety of woody plants (Mead 1969). Wilson and McPherson (1980) reported its occurrence on 85 species in 45 families in Illinois. It is widespread throughout Florida, even as a pest, and ranges across the U.S., south to Mexico, and north to Canada. Thus the positive response of this planthopper to burning is likely due to a complex set of factors.

Leaf beetles, which are also herbivores, significantly increased only in control plots (Fig. 5.4). Three leaf beetle species appear to contribute to the relatively higher density of control plots: *Metachroma pellucidum*, *M. quercatum*, and *Triachus atomus*. *Metachroma quercatum* is known to feed on oaks (Blake 1970), including turkey oak, and *M. pellucidum* has been collected on oaks (R. W. Flowers, Florida A&M University, pers. observ.). We note, however, that only very small numbers of *M. pellucidum* and *M. quercatum* are responsible for this increase. *Triachus atomus* is polyphagous and, therefore, not only associated with oaks (R. W. Flowers, pers. observ.).

We anticipated no great change in herbivore populations for the first year post-treatment (i.e., spring 1996) in felling/girdling plots, but other arthropods seeking open canopies or decaying slash should be attracted to the plots. The strongest responses to this treatment were by dance flies (Fig. 5.4), braconid wasps (Fig. 5.4), dance fly #1 (Fig. 5.6), and *Erythroneura* leafhoppers (Fig. 5.6). Larval dance flies are probably all predacious on other insects. Dance flies are also commonly found in moist spots near rotting wood and litter (Steyskal and Knutson 1981), both of which were abundant after this treatment. Over 90% of dance fly specimens collected were represented by a single morpho/species, tentatively identified as *Stilpon* sp. *Erythroneura* leafhoppers are herbivores. Other herbivores, grasshoppers and thrips (Figs. 5.5) showed some density increase in felling/girdling plots. Increased sunlight and young palatable foliage from hardwood resprouts were probably responsible for attracting herbivores to these plots.

ULW® application was predicted to enhance the density of families or morpho/species attracted to sunny conditions, decaying and abundant leaf litter, and dead hardwoods. We found two families that significantly increased in this treatment: clubionid spiders (Fig. 5.4) and psocids (Fig. 5.4). Clubionid spiders are hunters that live on foliage and the ground that spin tubular retreats in rolled leaves (Kaston 1978), which was an abundant substrate in ULW® plots compared to other plots (Chapter 3). Psocids appear ideally suited to the ULW® environment since they "occur on the bark or foliage of trees and shrubs, under bark or stones or in dead leaves" and "feed on algae, lichens, molds, cereals, pollen, fragments of dead insects, and similar materials" (Borror et al. 1989: 260).

Morpho/species Analysis. An important contribution of this study to sandhill arthropod ecology was the identification of 225 selected sandhill morpho/species and their use in statistical analyses. This effort may be unique in the longleaf pine literature. In the past, we could only test treatment effects at the family level (Provencher et al. 1996, 1997). Although family level analyses may reveal trends in biomass, they can be misleading because species within each family may not homogeneously respond to treatments. For example, two species of grasshoppers may show opposite and strong responses to fire, which could cause a non-significant treatment effect at the family level when there may have been two significant effects at the species level. On the other hand, the dominant morpho/species of a family may show convergent responses and, thus, justify testing treatment effects at the family level, which should minimize the statistical problem of analyzing morpho/species with small densities. For example, leafhoppers (Homoptera: Cicadellidae) responded positively to treatments, especially to fire and felling/girdling, but not significantly ($P < 0.13$; Table 5.1). Two dominant

leafhopper morpho/species showed marginally significant (leafhopper #28; Table 5.3) and significant (*Erythroneura* spp.; Fig. 5.6) responses to the same treatments. In this case, a multivariate test of treatment effects on both morpho/species could be a better method than a univariate test of their combined densities or biomass.

The results of our study have shown that, in some families, one morpho/species overwhelmingly dominates, and its statistical response matches that of its family. These morpho/species could thus deserve further consideration as indicators. The flatid planthopper *Metcalfa pruinosa* (Fig. 5.6), the sminthurid springtail *Sminthurus carolinensis* (Fig. 5.5), and dance fly #1 ($P < 0.0952$; Tables 5.3; Fig. 5.6) are such morpho/species that achieved higher densities in burn and/or felling/girdling plots.

ISSUES OF MANAGEMENT CONCERN

Positive responses of herbivores to burns should be the most important result for land managers for two reasons. First, grasshoppers account for >90% of the arthropod biomass we sampled (Provencher et al. 1997). Homopterans and spiders are other important sources of biomass. Therefore, the burn effect was distinctive among all treatments during the first post-treatment spring. (This does not, however, necessarily mean that wildlife are not eating arthropods that have not increased in response to treatments.) It is very likely that other herbivores, which did not show significant treatment effects, responded to burning and, thus, contributed to increased biomass (e.g., Homoptera families Aphididae and Cicadellidae; Tables 5.1-5.2). An increase in biomass due to fire should benefit wildlife in and out of the breeding season. Breeding quail (Brennan, *in press*), breeding turkey (Ehrlich et al. 1988), ground and herb-layer birds, hawking birds (e.g., loggerhead shrike [*Lanius ludovicianus*]), many woodpeckers, including red-cockaded woodpecker (Hooper 1996, Hanula and Franzreb 1995), reptiles, and kestrels (Terres 1991) feed on grasshoppers, homopterans, and many soft- and hard-bodied arthropods. During the breeding season, most bird species depend on arthropods for most of their food (reviewed in Terres 1991 and Ehrlich et al. 1988).

We investigated the relationships between arthropod densities or biomass and an array of variables that potentially explain some variation in red-cockaded woodpecker reproductive success. Like Hardesty, Gault, and Percival (1997), we found that ground cover (forb, graminoid, woody species, and bare ground) variables and plant species richness were more often correlated to arthropod density and biomass than any pine or hardwood variable before and after treatment application (Table 5.5a-b). (Paradoxically, greater bare ground coverage was associated with well-burned sites where herbaceous vegetation was abundant in the range of conditions we observed.) These results support the use of fire for management because these groundcover characteristics are increased by burning.

We do not suggest that managing for arthropod biomass is the only desirable goal. We suspect that increases in biomass following burning may be coupled to greater arthropod biodiversity from our observations in reference plots. Rare species, while not being sampled in numbers necessary for statistical analysis, are also important to monitor, because they may be the species most susceptible to habitat changes. Panzer et al. (1995) found that while the majority of prairie-and-savanna-inhabiting insects of the Chicago region were disturbance tolerant, perhaps 25% were remnant dependent, i.e., species limited in distribution to natural area remnants. They caution that the first step in evaluating the effects of management practices must be to identify and focus on remnant-dependent species. The relationship between arthropod biomass and biodiversity under fire management needs to be verified, however, so that increasing arthropod biomass is not accomplished at the expense of biodiversity.

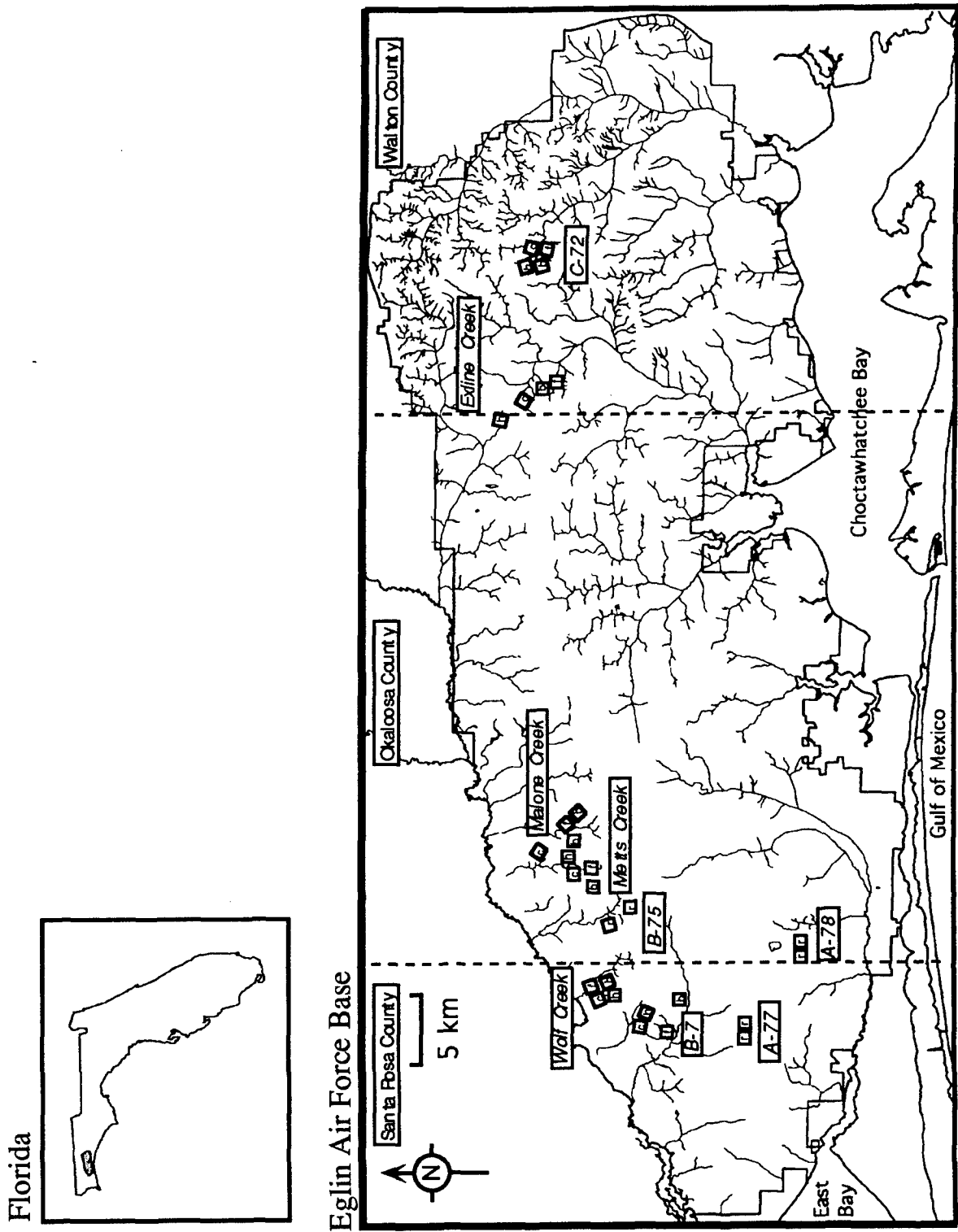


Fig. 5.1. Location of restoration and reference plots on Eglin Air Force Base, Florida. Small squares represent 200-acre plots. Legend: b = burn; c = control; f = felling/girdling; h = herbicide; r = reference.

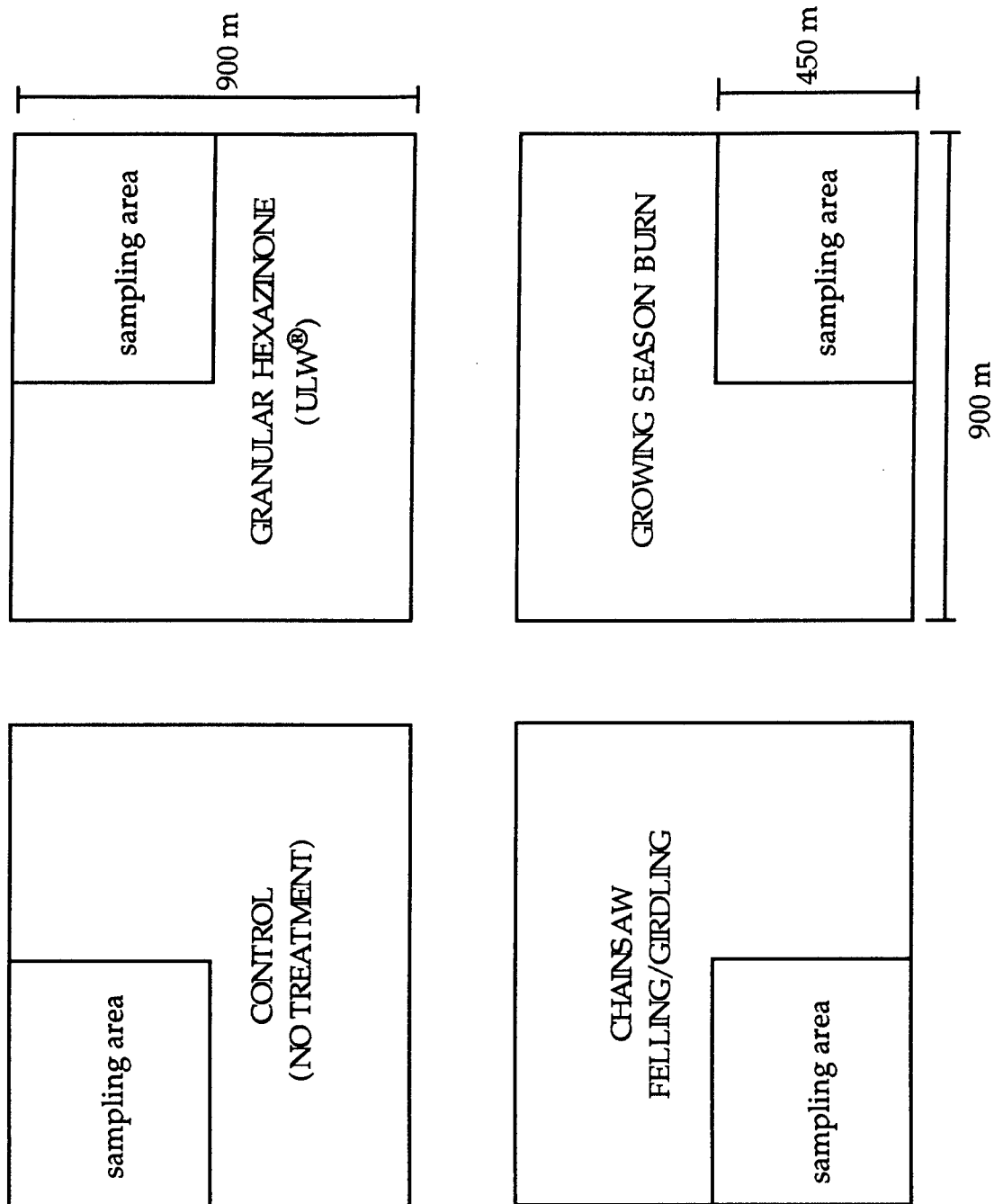
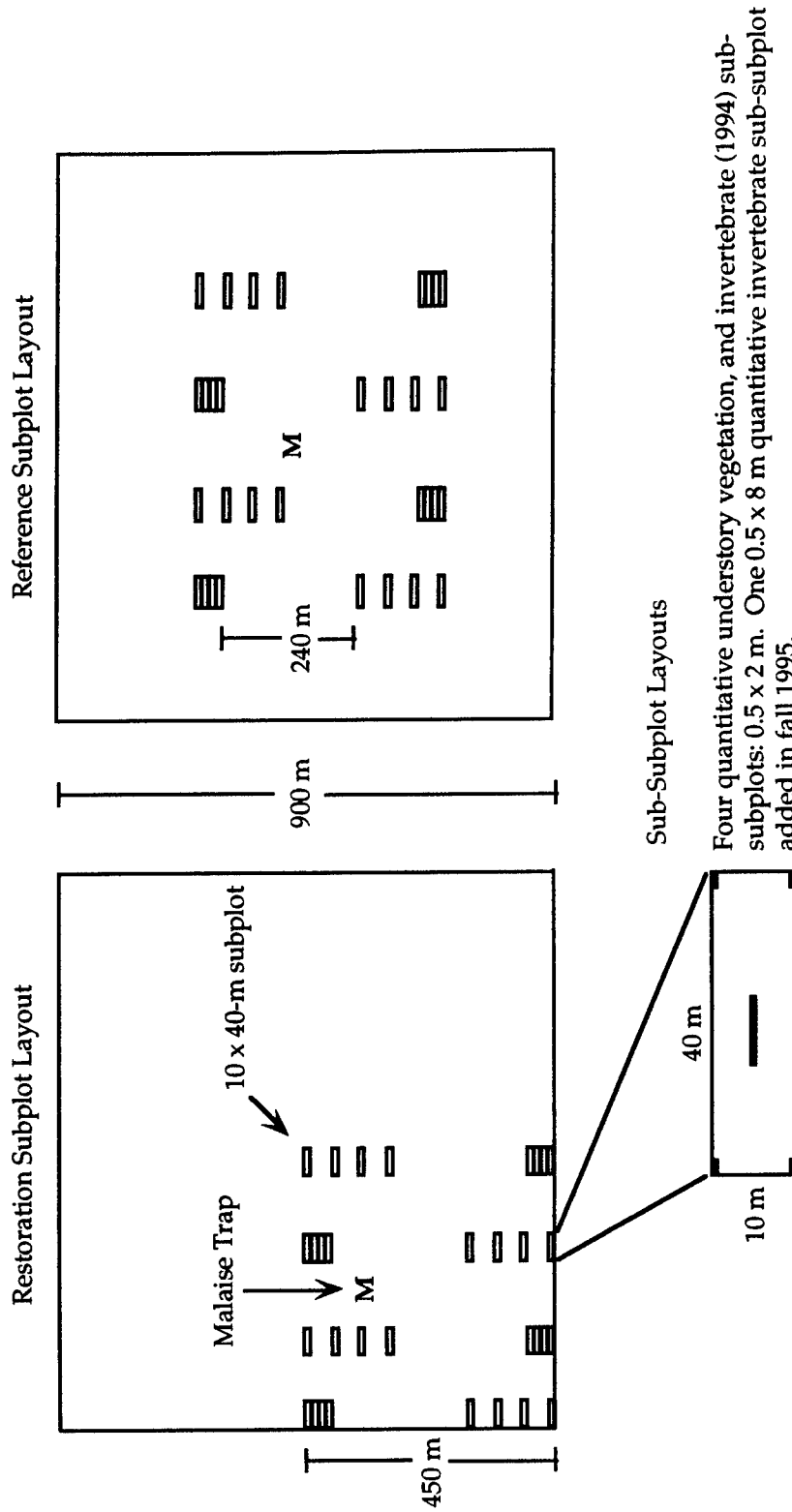


Fig. 5.2. Sample layout of 81-ha (200-acre) restoration plots and sampling areas in one of six blocks in a randomized complete block split-plot design consisting of four whole-plot treatments. See Fig. 5.3 for details of the sampling area.



Four quantitative understory vegetation, and invertebrate (1994) sub-subplots: 0.5 x 2 m. One 0.5 x 8 m quantitative invertebrate sub-subplot added in fall 1995.

Fig. 5.3. Restoration plot and reference plot subplot layout. Each plot is composed of 32, 10x40-m subplots arranged in four transects. Sampling step is 10 and 50 m. Distance between groups of four subplots per transect is 240 m. Transects are spaced along one plot edge (treatment plots) or centered in the plot (reference plots) and spaced at random distances >100 and < 135 m.

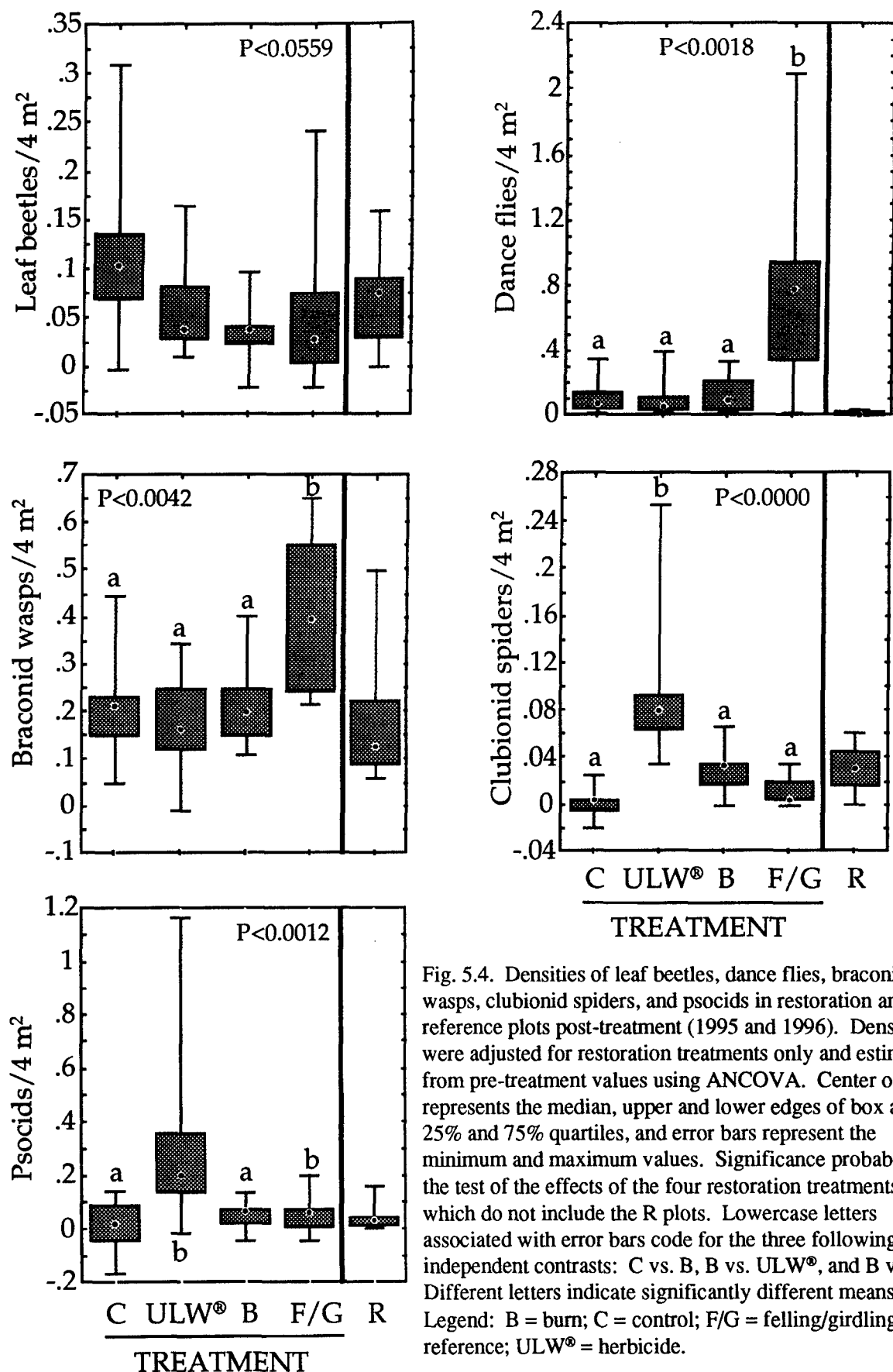


Fig. 5.4. Densities of leaf beetles, dance flies, braconid wasps, clubionid spiders, and psocids in restoration and reference plots post-treatment (1995 and 1996). Densities were adjusted for restoration treatments only and estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW[®], and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW[®] = herbicide.

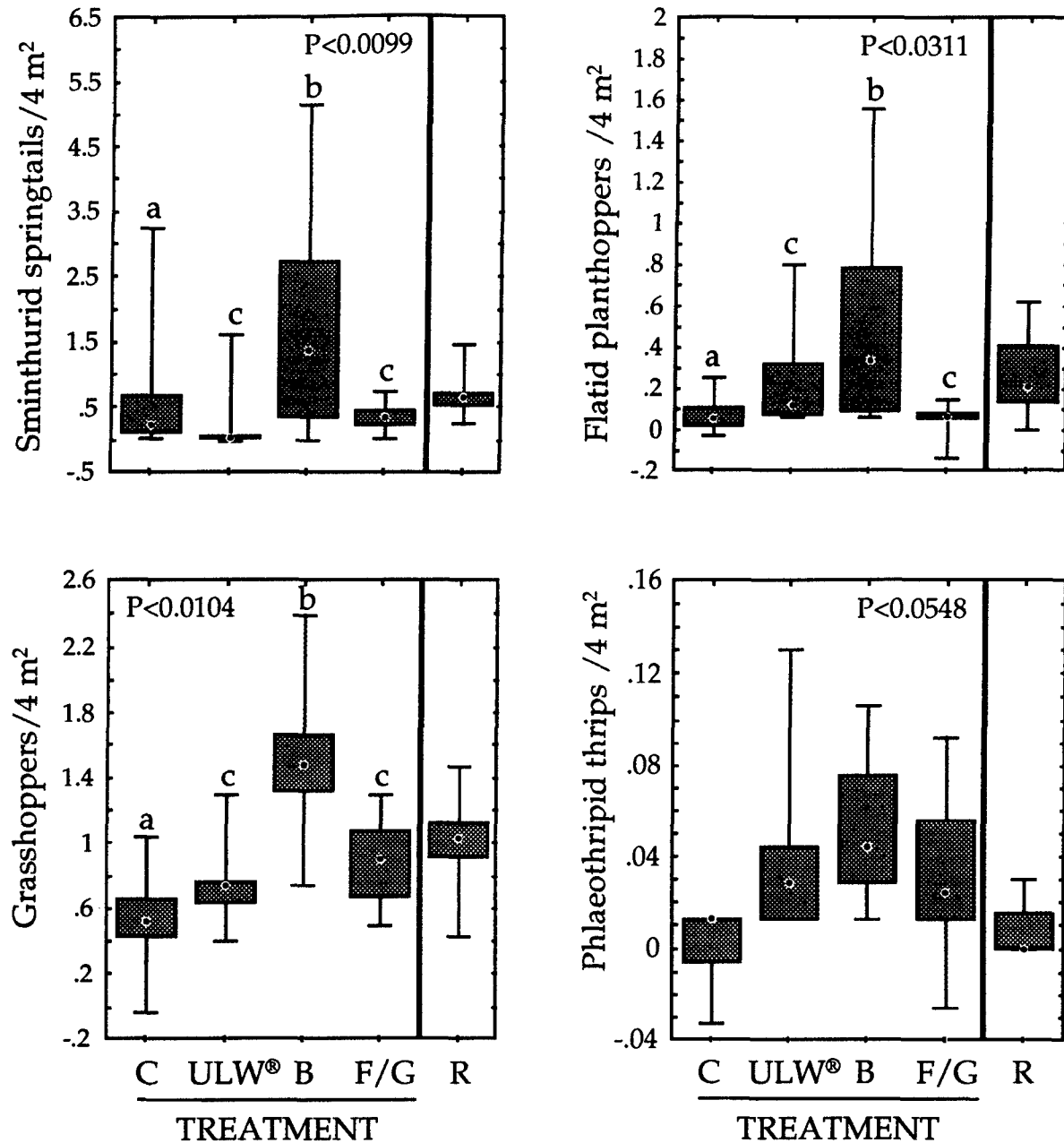


Fig. 5.5. Densities of sminthurid springtails, flatid planthoppers, grasshoppers, and phlaeothripid thrips in restoration and reference plots post-treatment (1995 and 1996). Densities were adjusted for restoration treatments only and estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW®, and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW® = herbicide.

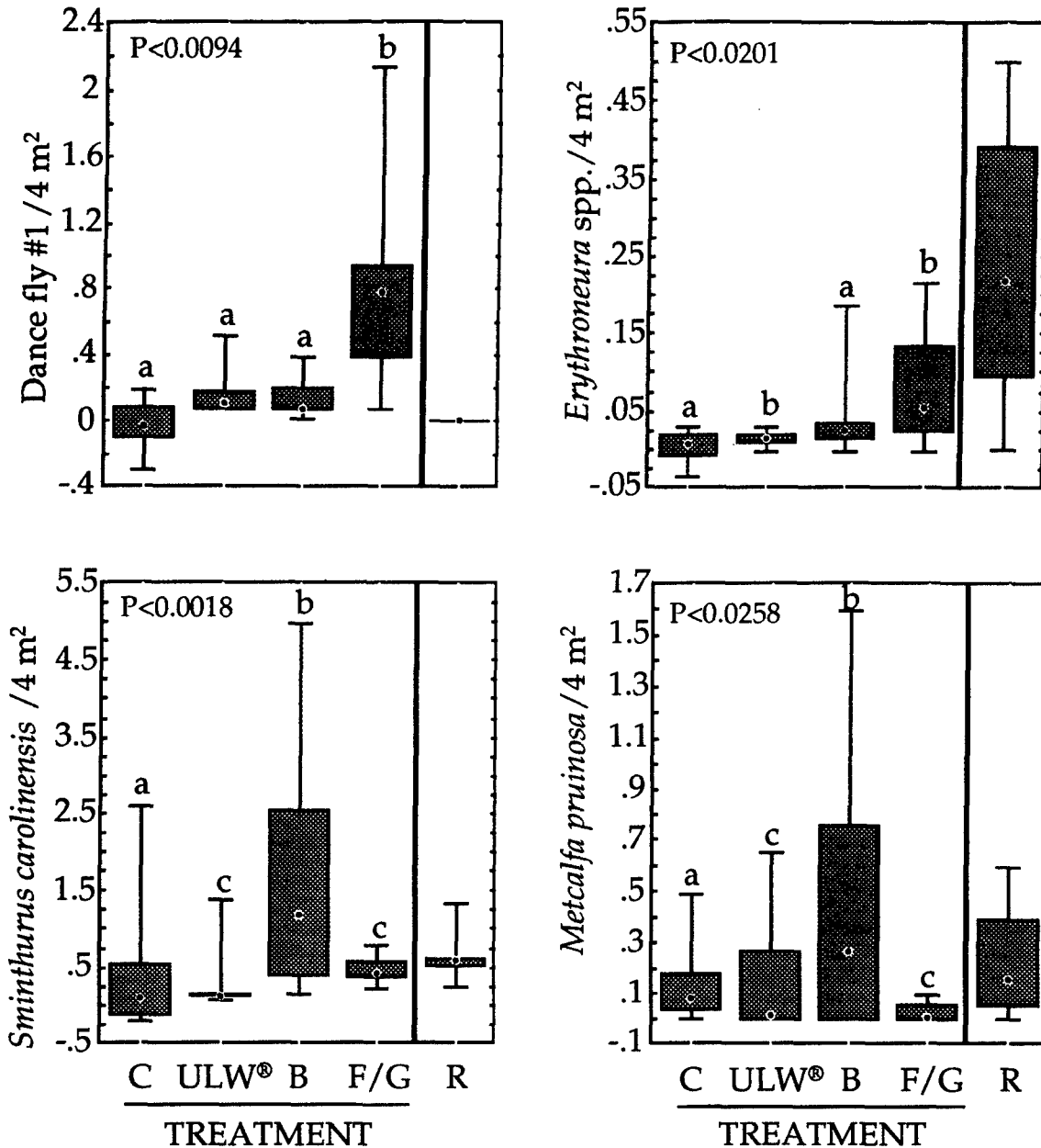


Fig. 5.6. Densities of dance fly #1, *Erythroneura* spp., *Sminthurus carolinensis*, and *Metcalfa pruinosa* in restoration and reference plots post-treatment (1995 and 1996). Densities were adjusted for restoration treatments only and estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW®, and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW® = herbicide.

Table 5.1. Two-way analyses of covariance for tests of restoration treatments and pre-treatment effects on arthropod family densities from the spring 1996 sampling period in mixed hardwoods and longleaf pine forests at Eglin Air Force Base, Florida. Restoration treatments are growing season burn, application of ULW[®] herbicide, hand felling and girdling of hardwoods and sand pine, and no-treatment control. The experimental design is a complete randomized block, split-plot design, but only the block design at the whole plot level is presented here. The covariate is the fall 1994 pre-treatment data. The error term is the mean square of the interaction of the block and restoration effects. Significance probabilities and sum of squares were calculated by a computer randomization ANCOVA based on 10,000 permutations. Calculations and tests followed Steel and Torrie (1980: 411-419, 215-217, 260). Arthropod densities were $\sqrt{(X + 0.5)}$ transformed to stabilize variances.

Source	Sum of squares	t-value	df	p-value
<u>Acari</u>				
Oribatida				
Block	0.0533		5	
Restoration	0.0414		3	0.2041
Pre-treatment	0.0045		1	0.9976
Error	0.1427		14	
Trombidiformes				
Block	0.2939		5	
Restoration	0.1794		3	0.5440
Pre-treatment	0.0000		1	0.9542
Error	0.4647		14	
<u>Araneae</u>				
Anyphaenidae				
Block	0.1517		5	
Restoration	0.0099		3	0.9974
Pre-treatment	0.0002		1	0.9058
Error	0.0848		14	
Araneidae				
Block	1.6543		5	
Restoration	0.9212		3	0.4489
Pre-treatment	0.4428		1	0.9999
Error	2.2543		14	
Clubionidae				
Block	0.0700		5	
Restoration	0.3475		3	0.0000
Pre-treatment	0.0036		1	0.5000
Error	0.2093		14	
Contrast				
C vs B†		-0.4646	1	0.1795
B vs F/G		0.2620	1	0.8205
B vs U		-1.1323	1	0.0000
Linyphiidae				
Block	0.1176		5	
Restoration	0.0059		3	0.9868
Pre-treatment	0.0006		1	0.9977
Error	0.0629		14	

† Abbreviations of treatments: B = burn; C = control; F/G = felling/girdling; U = ULW[®].

Table 5.1. Continued.

Source	Sum of squares	t-level	df	p-value
Micryphantidae				
Block	0.0587		5	
Restoration	0.0373		3	0.2793
Pre-treatment	0.0224		1	0.9968
Error	0.0556		14	
Mimetidae				
Block	0.0475		5	
Restoration	0.0193		3	0.2798
Pre-treatment	0.0001		1	0.8781
Error	0.0515		14	
Oxyopidae				
Block	0.1170		5	
Restoration	0.0168		3	0.7147
Pre-treatment	0.0093		1	0.9255
Error	0.1799		14	
Salticidae				
Block	1.0208		5	
Restoration	0.2199		3	0.4914
Pre-treatment	0.0853		1	0.9999
Error	0.5964		14	
Theridiidae				
Block	0.0100		5	
Restoration	0.0037		3	0.9280
Pre-treatment	0.0018		1	0.4812
Error	0.0482		14	
Thomisidae				
Block	5.3693		5	
Restoration	0.2930		3	0.9980
Pre-treatment	0.1001		1	0.9999
Error	3.9352		14	
<u>Coleoptera</u>				
Anobiidae				
Block	0.0085		5	
Restoration	0.0020		3	0.8039
Pre-treatment	0.0014		1	0.4880
Error	0.0482		14	
Bruchidae				
Block	0.0649		5	
Restoration	0.0074		3	0.7553
Pre-treatment	0.0545		1	0.5574
Error	0.0611		14	
Buprestidae				
Block	0.1404		5	
Restoration	0.1035		3	0.5192
Pre-treatment	0.0009		1	0.7999
Error	0.4619		14	
Chrysomelidae				
Block	0.2279		5	
Restoration	0.2138		3	0.0559

Table 5.1. Continued.

Source	Sum of squares	t-level	df	p-value
Pre-treatment	0.0631		1	0.9997
Error	0.5548		14	
Coccinellidae				
Block	0.1804		5	
Restoration	0.0846		3	0.0776
Pre-treatment	0.0231		1	0.9998
Error	0.3244		14	
Curculionidae				
Block	0.1097		5	
Restoration	0.0264		3	0.9216
Pre-treatment	0.0119		1	0.7058
Error	0.0777		14	
Elateridae				
Block	0.0541		5	
Restoration	0.0206		3	0.5331
Pre-treatment	0.0152		1	0.2204
Error	0.0862		14	
Melyridae				
Block	5.0212		5	
Restoration	3.0531		3	0.2634
Pre-treatment	0.0038		1	0.9999
Error	5.8354		14	
Mordellidae				
Block	2.2252		5	
Restoration	0.6026		3	0.0816
Pre-treatment	0.1560		1	0.9983
Error	0.8890		14	
Collembola				
Entomobryidae				
Block	0.0260		5	
Restoration	0.0298		3	0.2775
Pre-treatment	0.0070		1	0.9946
Error	0.2246		14	
Sminthuridae				
Block	31.7984		5	
Restoration	18.2843		3	0.0099
Pre-treatment	0.0956		1	0.5000
Error	37.1106		14	
Contrast				
C vs B	-0.662		1	0.0000
B vs F/G	0.7221		1	0.0000
B vs U	0.8349		1	0.0002
Diptera				
Agromyzidae				
Block	0.0631		5	
Restoration	0.0182		3	0.9900
Pre-treatment	0.0006		1	0.9965
Error	0.3034		14	

Table 5.1. Continued.

Source	Sum of squares	t-level	df	p-value
Asilidae				
Block	1.0347		5	
Restoration	0.3342		3	0.2579
Pre-treatment	0.0321		1	0.9970
Error	0.5198		14	
Cecidomyiidae				
Block	9.9632		5	
Restoration	3.4841		3	0.8185
Pre-treatment	2.2101		1	0.9999
Error	15.5618		14	
Ceratopogonidae				
Block	1.3880		5	
Restoration	0.3429		3	0.7775
Pre-treatment	0.0004		1	0.9997
Error	2.8177		14	
Chironomidae				
Block	3.9019		5	
Restoration	1.3761		3	0.4495
Pre-treatment	0.1072		1	0.9997
Error	5.0020		14	
Chloropidae				
Block	1.1821		5	
Restoration	0.0817		3	0.9511
Pre-treatment	0.1458		1	0.9999
Error	0.7017		14	
Dolichopodidae				
Block	2.5278		5	
Restoration	0.9108		3	0.9493
Pre-treatment	0.3492		1	0.9999
Error	1.8580		14	
Empididae				
Block	4.7749		5	
Restoration	4.9638		3	0.0018
Pre-treatment	0.0496		1	0.5000
Error	3.5793		14	
Contrast				
C vs B		-0.0164	1	0.2659
B vs F/G		-1.2244	1	0.0000
B vs U		0.1163	1	0.3594
Lauxaniidae				
Block	1.6513		5	
Restoration	0.4891		3	0.1704
Pre-treatment	0.0170		1	0.9999
Error	2.0582		14	
Milichiidae				
Block	0.4926		5	
Restoration	0.1070		3	0.7946
Pre-treatment	0.0064		1	0.9818
Error	0.5645		14	

Table 5.1. Continued.

Source	Sum of squares	t-level	df	p-value
Mycetophilidae				
Block	0.0336		5	
Restoration	0.0230		3	0.3151
Pre-treatment	0.0016		1	0.5533
Error	0.0833		14	
Phoridae				
Block	0.1416		5	
Restoration	0.9966		3	0.0945
Pre-treatment	0.0249		1	0.9999
Error	2.7211		14	
Sciaridae				
Block	0.2856		5	
Restoration	0.1681		3	0.6311
Pre-treatment	0.0030		1	0.9997
Error	0.9665		14	
Simuliidae				
Block	1.7602		5	
Restoration	0.2055		3	0.9777
Pre-treatment	0.0015		1	0.9999
Error	1.3416		14	
Tabanidae				
Block	0.1122		5	
Restoration	0.0694		3	0.0811
Pre-treatment	0.0127		1	0.1566
Error	0.2323		14	
Tachinidae				
Block	0.0145		5	
Restoration	0.0013		3	0.8601
Pre-treatment	0.0006		1	0.2357
Error	0.0309		14	
Hemiptera				
Coreidae				
Block	0.0397		5	
Restoration	0.0151		3	0.7385
Pre-treatment	0.0418		1	0.3734
Error	0.1749		14	
Miridae				
Block	0.4166		5	
Restoration	0.0146		3	0.9830
Pre-treatment	0.1041		1	0.9914
Error	0.5604		14	
Pentatomidae				
Block	0.0217		5	
Restoration	0.0101		3	0.4544
Pre-treatment	0.0030		1	0.5239
Error	0.0761		14	
Homoptera				
Acanaloniidae				
Block	0.0740		5	

Table 5.1. Continued.

Source	Sum of squares	t-level	d f	p-value
Restoration	0.1262		3	0.0691
Pre-treatment	0.0048		1	0.9598
Error	0.1677		14	
Aleyrodidae				
Block	0.0251		5	
Restoration	0.0043		3	0.9350
Pre-treatment	0.0002		1	0.5803
Error	0.0882		14	
Aphididae				
Block	1.1437		5	
Restoration	0.6473		3	0.1186
Pre-treatment	0.0000		1	0.9999
Error	1.3813		14	
Cicadellidae				
Block	24.3466		5	
Restoration	5.2365		3	0.1307
Pre-treatment	3.6602		1	0.9999
Error	17.7616		14	
Cixiidae				
Block	0.3726		5	
Restoration	0.2115		3	0.9017
Pre-treatment	0.0046		1	0.9997
Error	0.4697		14	
Flatidae				
Block	5.209		5	
Restoration	2.5556		3	0.0311
Pre-treatment	0.037		1	0.5000
Error	5.3485		14	
Contrast				
C vs B		-0.6408	1	0.0000
B vs F/G		0.8806	1	0.0000
B vs U		0.3871	1	0.0229
Issidae				
Block	0.8956		5	
Restoration	0.6880		3	0.0784
Pre-treatment	0.0016		1	0.9993
Error	1.8066		14	
Psyllidae				
Block	2.5806		5	
Restoration	0.3204		3	0.8477
Pre-treatment	0.0161		1	0.9998
Error	0.8517		14	
Hymenoptera				
Braconidae				
Block	0.59		5	
Restoration	1.6577		3	0.0042
Pre-treatment	0.2023		1	0.5000
Error	3.5966		14	

Table 5.1. Continued.

Source	Sum of squares	t-level	df	p-value
Contrast				
C vs B		-0.0319	1	0.5857
B vs F/G		-0.6767	1	0.0000
B vs U		0.1714	1	0.1619
Braconidae: Cheloninae				
Block	0.0396		5	
Restoration	0.0177		3	0.4803
Pre-treatment	0.0004		1	0.3144
Error	0.1240		14	
Ceraphronidae				
Block	0.0792		5	
Restoration	0.0201		3	0.6095
Pre-treatment	0.0010		1	0.8776
Error	0.1069		14	
Cynipidae				
Block	0.3102		5	
Restoration	0.0171		3	0.9928
Pre-treatment	0.0450		1	0.9480
Error	0.2685		14	
Encyrtidae				
Block	1.1223		5	
Restoration	0.2511		3	0.3563
Pre-treatment	0.0440		1	0.9999
Error	1.3344		14	
Eucharitidae				
Block	0.0574		5	
Restoration	0.0020		3	0.9742
Pre-treatment	0.0022		1	0.4156
Error	0.0707		14	
Eucoilidae				
Block	0.0711		5	
Restoration	0.0733		3	0.6277
Pre-treatment	0.0130		1	0.7359
Error	0.2315		14	
Eulophidae				
Block	9.2754		5	
Restoration	0.1681		3	0.9981
Pre-treatment	0.0291		1	0.9999
Error	4.3419		14	
Eurytomidae				
Block	0.0707		5	
Restoration	0.0445		3	0.4204
Pre-treatment	0.0073		1	0.7393
Error	0.3053		14	
Formicidae				
Block	4.5777		5	
Restoration	4.8762		3	0.3141
Pre-treatment	1.4535		1	0.9999
Error	24.3832		14	

Table 5.1. Continued.

Source	Sum of squares	t-level	df	p-value
Ichneumonidae				
Block	0.0345		5	
Restoration	0.0436		3	0.1915
Pre-treatment	0.0229		1	0.7668
Error	0.0767		14	
Mymaridae				
Block	0.8079		5	
Restoration	0.2838		3	0.2187
Pre-treatment	0.0213		1	0.9996
Error	0.8739		14	
Platygastridae				
Block	8.7624		5	
Restoration	2.1782		3	0.2505
Pre-treatment	0.3466		1	0.5000
Error	6.9491		14	
Pteromalidae				
Block	0.0869		5	
Restoration	0.0735		3	0.6788
Pre-treatment	0.0031		1	0.9998
Error	0.5123		14	
Scelionidae				
Block	0.6713		5	
Restoration	0.0790		3	0.7588
Pre-treatment	0.0057		1	0.9997
Error	0.1913		14	
Tenthredinidae				
Block	8.4996		5	
Restoration	2.9581		3	0.1890
Pre-treatment	0.7968		1	0.9993
Error	11.5134		14	
Torymidae				
Block	0.0828		5	
Restoration	0.0255		3	0.5615
Pre-treatment	0.0023		1	0.9985
Error	0.2335		14	
<u>Lepidoptera</u>				
Geometridae				
Block	1.8341		5	
Restoration	0.3271		3	0.4223
Pre-treatment	0.1062		1	0.9983
Error	0.9402		14	
Psychidae				
Block	0.0205		5	
Restoration	0.0061		3	0.9716
Pre-treatment	0.0016		1	0.1108
Error	0.0559		14	
<u>Orthoptera</u>				
Acrididae				
Block	21.7485		5	

Table 5.1. Continued.

Source	Sum of squares	t-level	df	p-value
Restoration	12.4772		3	0.0104
Pre-treatment	1.0761		1	0.5000
Error	11.6627		14	
Contrast				
C vs B		-1.3227	1	0.0000
B vs F/G		0.9051	1	0.0000
B vs U		0.9561	1	0.0001
Gryllidae				
Block	0.5730		5	
Restoration	0.1929		3	0.5341
Pre-treatment	0.0170		1	0.9999
Error	0.8587		14	
Tettigoniidae				
Block	0.1649		5	
Restoration	2.1050		3	0.5919
Pre-treatment	0.0841		1	0.9999
Error	5.1028		14	
<u>Psocoptera</u>				
Psocidae				
Block	1.0371		5	
Restoration	1.7669		3	0.0012
Pre-treatment	0.2966		1	0.5000
Error	3.0059		14	
Contrast				
C vs B		-0.1111	1	0.9426
B vs F/G		-0.0279	1	0.0032
B vs U		-0.9806	1	0.0000
<u>Thysanoptera</u>				
Phlaeothripidae				
Block	0.1507		5	
Restoration	0.1003		3	0.0548
Pre-treatment	0.0865		1	0.6147
Error	0.2257		14	

Table 5.2. Mean (± 1 standard error) of arthropod family densities (individuals/4m²) per 81-ha (200-acre) restoration treatments and reference plots at Eglin Air Force Base, Florida. Sample size = 6 blocks.

Taxon	Treatment				Reference
	Control	ULW [®]	Burn	Felling	
Spring 1995					
<u>Acari</u>					
Liodoidea	0.010±0.006	0.035±0.016	0.010±0.006	0.005±0.005	0.015±0.010
Oribatida	0.050±0.017	0.045±0.017	0.040±0.017	0.040±0.013	0.328±0.235
Trombidiformes	0.040±0.015	0.005±0.005	0.020±0.013	0.030±0.015	0.082±0.048
<u>Araneae</u>					
Agelenidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.015±0.010
Anyphaenidae	0.123±0.026	0.000±0.000	0.010±0.006	0.040±0.020	0.040±0.017
Araneidae	0.173±0.021	0.152±0.029	0.123±0.029	0.122±0.027	0.223±0.058
Clubionidae	0.057±0.028	0.015±0.007	0.010±0.006	0.005±0.005	0.055±0.009
Gnaphosidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Linyphiidae	0.035±0.018	0.025±0.009	0.020±0.010	0.037±0.027	0.110±0.046
Lycosidae	0.000±0.000	0.000±0.000	0.005±0.005	0.005±0.005	0.005±0.005
Lyssomanidae	0.020±0.006	0.010±0.006	0.005±0.005	0.020±0.015	0.000±0.000
Micryphantidae	0.055±0.014	0.050±0.013	0.045±0.022	0.040±0.018	0.065±0.018
Mimetidae	0.035±0.014	0.015±0.007	0.025±0.014	0.020±0.010	0.015±0.007
Nesticidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Oxyopidae	0.067±0.043	0.015±0.010	0.000±0.000	0.015±0.010	0.077±0.024
Philodromidae	0.000±0.000	0.005±0.005	0.000±0.000	0.005±0.005	0.037±0.025
Pisauridae	0.065±0.022	0.000±0.000	0.005±0.005	0.020±0.020	0.037±0.031
Salticidae	0.518±0.120	0.155±0.033	0.182±0.034	0.150±0.051	0.308±0.106
Theridiidae	0.020±0.015	0.005±0.005	0.015±0.010	0.010±0.010	0.015±0.007
Thomisidae	0.668±0.136	0.123±0.025	0.140±0.037	0.228±0.117	0.443±0.138
<u>Blattaria</u>					
Blattellidae	0.005±0.005	0.000±0.000	0.005±0.005	0.005±0.005	0.005±0.005
<u>Coleoptera</u>					
Alleculidae	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
Anobiidae	0.015±0.007	0.005±0.005	0.005±0.005	0.005±0.005	0.005±0.005
Anthicidae	0.005±0.005	0.010±0.006	0.005±0.005	0.010±0.010	0.000±0.000
Anthribidae	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.100±0.037
Bruchidae	0.015±0.010	0.000±0.000	0.000±0.000	0.000±0.000	0.030±0.013
Buprestidae	0.010±0.006	0.010±0.006	0.005±0.005	0.010±0.006	0.030±0.019
Cantharidae	0.015±0.007	0.015±0.007	0.062±0.029	0.062±0.023	0.000±0.000
Carabidae	0.000±0.000	0.005±0.005	0.000±0.000	0.005±0.005	0.000±0.000
Cerambycidae	0.000±0.000	0.000±0.000	0.000±0.000	0.068±0.068	0.000±0.000
Chrysomelidae	0.035±0.014	0.040±0.018	0.030±0.019	0.035±0.020	0.060±0.017
Alticinae	0.000±0.000	0.005±0.005	0.005±0.005	0.020±0.015	0.083±0.048
Cassidinae	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Chlamisinae	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.010±0.006
Cleridae	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005	0.005±0.005
Coccinellidae	0.073±0.043	0.068±0.043	0.035±0.009	0.050±0.010	0.040±0.018
Epilachinae	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
Colydiidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005

Table 5.2. Continued.

Taxon	Treatment				Reference
	Control	ULW [®]	Burn	Felling	
Corylophidae	0.000±0.000	0.005±0.005	0.000±0.000	0.005±0.005	0.000±0.000
Cryptophagidae	0.005±0.005	0.015±0.010	0.020±0.015	0.015±0.007	0.015±0.010
Curculionidae	0.015±0.010	0.005±0.005	0.020±0.006	0.020±0.013	0.062±0.039
Cossoninae	0.000±0.000	0.000±0.000	0.005±0.005	0.005±0.005	0.000±0.000
Elateridae	0.035±0.018	0.000±0.000	0.015±0.007	0.010±0.006	0.065±0.018
Erotylidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005
Euglenidae	0.020±0.020	0.020±0.015	0.005±0.005	0.005±0.005	0.000±0.000
Histeridae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Lathridiidae	0.020±0.010	0.005±0.005	0.005±0.005	0.000±0.000	0.020±0.015
Lycidae	0.000±0.000	0.005±0.005	0.000±0.000	0.005±0.005	0.000±0.000
Melandryidae	0.000±0.000	0.010±0.010	0.000±0.000	0.047±0.047	0.000±0.000
Scraptiinae	0.000±0.000	0.020±0.010	0.010±0.006	0.005±0.005	0.000±0.000
Melyridae	0.147±0.047	0.057±0.025	0.062±0.029	0.260±0.120	0.010±0.010
Malachiinae	0.068±0.068	0.000±0.000	0.000±0.000	0.000±0.000	0.040±0.020
Mordellidae	0.093±0.037	0.172±0.061	0.093±0.042	0.133±0.034	0.032±0.026
Oedemeridae	0.000±0.000	0.000±0.000	0.010±0.010	0.010±0.010	0.000±0.000
Phalacridae	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.005±0.005
Rhizophagidae	0.000±0.000	0.010±0.010	0.000±0.000	0.000±0.000	0.000±0.000
Scarabaeidae	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005	0.005±0.005
Scydmaenidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Staphylinidae	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.005±0.005
Tenebrionidae	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
<u>Collembola</u>					
Entomobryidae	0.025±0.012	0.057±0.023	0.040±0.025	0.050±0.023	0.118±0.044
Sminthuridae	0.625±0.108	0.150±0.051	0.185±0.120	0.103±0.053	0.948±0.371
<u>Diptera</u>					
Agromyzidae	0.005±0.005	0.025±0.009	0.005±0.005	0.000±0.000	0.025±0.020
Phytomyzidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Anthomyiidae	0.000±0.000	0.010±0.006	0.005±0.005	0.000±0.000	0.005±0.005
Asilidae	0.015±0.007	0.030±0.020	0.030±0.015	0.040±0.021	0.005±0.005
Leptogastrinae	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Bombyliidae	0.005±0.005	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
Cecidomyiidae	0.740±0.261	1.218±0.418	0.740±0.119	0.683±0.217	0.448±0.169
Ceratopogonidae	0.122±0.039	0.035±0.018	0.115±0.041	0.088±0.043	0.093±0.058
Chironomidae	0.413±0.341	0.055±0.018	0.138±0.049	0.155±0.063	0.135±0.086
Chloropidae	0.155±0.036	0.140±0.083	0.093±0.032	0.067±0.021	0.532±0.155
Clusiidae	0.025±0.012	0.000±0.000	0.010±0.010	0.000±0.000	0.000±0.000
Culicidae	0.000±0.000	0.010±0.006	0.010±0.006	0.005±0.005	0.005±0.005
Dolichopodidae	1.025±0.252	0.147±0.037	0.333±0.179	0.238±0.082	0.478±0.148
Drosophilidae	0.005±0.005	0.010±0.006	0.005±0.005	0.005±0.005	0.030±0.019
Empididae	0.287±0.194	0.030±0.019	0.027±0.027	0.077±0.056	0.030±0.015
Ephydriidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Lauxaniidae	0.057±0.025	0.115±0.048	0.307±0.176	0.163±0.062	0.005±0.005
Milichiidae	0.070±0.015	0.025±0.014	0.050±0.013	0.005±0.005	0.015±0.015

Table 5.2. Continued.

Taxon	Treatment				Reference
	Control	ULW ^a	Burn	Felling	
Muscidae	0.010±0.006	0.072±0.035	0.040±0.021	0.035±0.018	0.005±0.005
Mycetophilidae	0.050±0.020	0.035±0.014	0.155±0.084	0.098±0.048	0.000±0.000
Otitidae	0.015±0.010	0.000±0.000	0.000±0.000	0.000±0.000	0.015±0.007
Periscelididae	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
Phoridae	0.480±0.095	0.890±0.301	0.787±0.135	0.745±0.151	0.530±0.196
Pipunculidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005
Platystomatidae	0.037±0.037	0.000±0.000	0.042±0.036	0.000±0.000	0.197±0.108
Psychidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Sarcophagidae	0.010±0.006	0.005±0.005	0.000±0.000	0.005±0.005	0.000±0.000
Scatopsidae	0.005±0.005	0.005±0.005	0.005±0.005	0.000±0.000	0.010±0.010
Sciaridae	0.143±0.050	0.212±0.103	0.305±0.112	0.187±0.078	0.045±0.010
Simuliidae	0.040±0.020	0.088±0.060	0.015±0.010	0.040±0.021	0.135±0.040
Sphaeroceridae	0.000±0.000	0.005±0.005	0.015±0.010	0.005±0.005	0.000±0.000
Tabanidae	0.108±0.040	0.000±0.000	0.010±0.006	0.035±0.014	0.040±0.021
Tachinidae	0.015±0.010	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Tephritidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.010
Therevidae	0.000±0.000	0.010±0.010	0.000±0.000	0.000±0.000	0.005±0.005
Tipulidae	0.015±0.010	0.010±0.006	0.035±0.009	0.072±0.048	0.000±0.000
Hemiptera					
Berytidae	0.010±0.006	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
Coreidae	0.035±0.020	0.025±0.020	0.015±0.010	0.020±0.010	0.005±0.005
Lygaeidae	0.015±0.015	0.015±0.015	0.000±0.000	0.000±0.000	0.108±0.048
Miridae	0.255±0.207	0.042±0.030	0.030±0.019	0.030±0.013	0.177±0.054
Pentatomidae	0.010±0.010	0.010±0.010	0.000±0.000	0.000±0.000	0.035±0.009
Reduviidae	0.025±0.014	0.015±0.010	0.010±0.006	0.020±0.020	0.030±0.011
Emesinae	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Phymatinae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Rhopalidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Tingidae	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.025±0.020
Homoptera					
Acanaloniidae	0.020±0.010	0.057±0.030	0.050±0.015	0.030±0.011	0.088±0.047
Achilidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Aleyrodidae	0.010±0.006	0.020±0.020	0.030±0.011	0.020±0.010	0.035±0.009
Aphididae	0.665±0.617	0.802±0.784	0.010±0.010	0.177±0.124	0.640±0.260
Cercopidae	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Cicadellidae	0.855±0.054	0.850±0.126	0.562±0.097	0.682±0.132	1.663±0.449
Cixiidae	0.010±0.010	0.147±0.063	0.103±0.031	0.055±0.018	0.062±0.046
Coccoidea	0.005±0.005	0.010±0.006	0.000±0.000	0.000±0.000	0.015±0.010
Delphacidae	0.005±0.005	0.010±0.006	0.000±0.000	0.005±0.005	0.108±0.038
Derbidae	0.000±0.000	0.010±0.010	0.000±0.000	0.000±0.000	0.010±0.010
Dictyopharidae	0.015±0.007	0.000±0.000	0.005±0.005	0.010±0.010	0.068±0.045
Flatidae	0.270±0.092	0.063±0.036	0.105±0.048	0.103±0.070	0.817±0.439
Fulgoroidea	0.035±0.012	0.123±0.042	0.062±0.022	0.140±0.047	0.072±0.043
Fulgoridae	0.005±0.005	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Issidae	0.055±0.022	0.005±0.005	0.030±0.020	0.015±0.010	0.103±0.054

Table 5.2. Continued.

Taxon	Treatment				Reference
	Control	ULW®	Burn	Felling	
Membracidae	0.010±0.006	0.015±0.010	0.010±0.010	0.020±0.015	0.045±0.019
Psyllidae	0.145±0.071	0.010±0.010	0.010±0.006	0.010±0.010	0.057±0.028
<u>Hymenoptera</u>					
Andrenidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Aphelinidae	0.040±0.015	0.135±0.111	0.030±0.013	0.050±0.015	0.015±0.015
Bethylidae	0.025±0.014	0.000±0.000	0.005±0.005	0.005±0.005	0.015±0.010
Braconidae	0.270±0.041	0.208±0.060	0.182±0.030	0.167±0.027	0.233±0.117
Alysiinae	0.020±0.015	0.025±0.016	0.020±0.015	0.025±0.014	0.005±0.005
Cheloninae	0.015±0.010	0.000±0.000	0.000±0.000	0.010±0.010	0.005±0.005
Ceraphronidae	0.100±0.032	0.045±0.022	0.045±0.017	0.075±0.017	0.088±0.065
Chalcidoidea	0.020±0.010	0.010±0.010	0.015±0.007	0.005±0.005	0.020±0.015
Chrysidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Crabronidae	0.010±0.010	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Cynipidae	0.015±0.010	0.040±0.010	0.065±0.014	0.080±0.015	0.005±0.005
Diapriidae	0.000±0.000	0.010±0.006	0.000±0.000	0.005±0.005	0.005±0.005
Belytinae	0.005±0.005	0.025±0.009	0.025±0.014	0.015±0.007	0.000±0.000
Dryinidae	0.005±0.005	0.015±0.010	0.025±0.009	0.010±0.010	0.015±0.007
Elasmidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.025±0.020
Embolemidae	0.000±0.000	0.000±0.000	0.005±0.005	0.005±0.005	0.000±0.000
Encyrtidae	0.117±0.016	0.113±0.046	0.097±0.024	0.093±0.026	0.102±0.027
Eucharitidae	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.025±0.014
Eucoilidae	0.147±0.035	0.025±0.014	0.020±0.010	0.040±0.018	0.020±0.010
Eulophidae	0.438±0.112	0.292±0.060	0.262±0.052	0.275±0.090	0.520±0.274
Euderinae	0.000±0.000	0.010±0.010	0.000±0.000	0.000±0.000	0.000±0.000
Eupelmidae	0.010±0.006	0.020±0.006	0.020±0.010	0.040±0.018	0.035±0.012
Eurytomidae	0.030±0.015	0.020±0.010	0.062±0.033	0.035±0.018	0.040±0.006
Evaniidae	0.025±0.009	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Figitidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.020±0.010
Formicidae	1.083±0.274	1.093±0.235	0.832±0.104	1.090±0.196	0.858±0.161
Halictidae	0.020±0.015	0.000±0.000	0.010±0.006	0.000±0.000	0.015±0.010
Ichneumonidae	0.015±0.007	0.035±0.012	0.062±0.023	0.087±0.046	0.040±0.015
Mymaridae	0.040±0.017	0.030±0.013	0.020±0.010	0.055±0.014	0.167±0.053
Ormyridae	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.006	0.015±0.010
Pergidae	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
Perilampidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Platygastridae	0.293±0.160	0.442±0.115	0.447±0.150	0.422±0.101	0.410±0.107
Pompilidae	0.010±0.010	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Proctotrupidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Pteromalidae	0.085±0.014	0.052±0.024	0.055±0.009	0.040±0.013	0.102±0.050
Cleonyminae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Scelionidae	0.098±0.025	0.065±0.018	0.082±0.031	0.143±0.059	0.275±0.105
Signiphoridae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.010
Symphyla	0.000±0.000	0.010±0.010	0.010±0.010	0.000±0.000	0.000±0.000
Tenthredinidae	0.015±0.010	0.398±0.214	0.113±0.058	0.093±0.060	0.015±0.010
Tiphiidae	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005	0.010±0.006

Table 5.2. Continued.

Taxon	Treatment				Reference
	Control	ULW*	Burn	Felling	
Torymidae	0.025±0.012	0.000±0.000	0.000±0.000	0.010±0.010	0.055±0.014
Trichogrammatidae	0.020±0.010	0.005±0.005	0.015±0.010	0.010±0.006	0.020±0.015
Vespidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
<u>Lepidoptera</u>					
Geometridae	0.020±0.010	0.035±0.014	0.097±0.045	0.045±0.022	0.128±0.042
Lycaenidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Noctuidae	0.005±0.005	0.010±0.010	0.020±0.010	0.000±0.000	0.005±0.005
Notodontidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.015±0.015
Psychidae	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.062±0.040
<u>Mantodea</u>					
Mantidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.015±0.010
<u>Microcoryphia</u>					
Meinertellidae	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<u>Neuroptera</u>					
Ascalaphidae	0.027±0.027	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
Chrysopidae	0.020±0.015	0.010±0.006	0.000±0.000	0.005±0.005	0.000±0.000
Coniopterygidae	0.000±0.000	0.005±0.005	0.005±0.005	0.005±0.005	0.010±0.010
Hemerobiidae	0.005±0.005	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Myrmeliontidae	0.005±0.005	0.000±0.000	0.005±0.005	0.000±0.000	0.010±0.006
<u>Odonata</u>					
Zygoptera	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.015±0.015
<u>Orthoptera</u>					
Acrididae	0.655±0.099	0.348±0.120	0.462±0.164	0.323±0.132	0.655±0.215
Romaliinae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Gryllidae	0.182±0.026	0.057±0.028	0.087±0.030	0.162±0.066	0.248±0.123
Tettigoniidae	0.272±0.038	0.098±0.040	0.082±0.028	0.097±0.019	0.417±0.179
Oecanthinae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.010
<u>Psocoptera</u>					
Psocidae	0.030±0.011	0.005±0.005	0.020±0.010	0.020±0.010	0.000±0.000
<u>Thysanoptera</u>					
Phlaeothripidae	0.015±0.010	0.005±0.005	0.000±0.000	0.020±0.010	0.030±0.015
Spring 1996					
<u>Acari</u>					
Liodoidea	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Oribatida	0.010±0.010	0.040±0.010	0.015±0.015	0.025±0.009	0.010±0.006
Trombidiformes	0.025±0.012	0.098±0.059	0.005±0.005	0.030±0.013	0.050±0.020
Tydeoidea	0.000±0.000	0.000±0.000	0.010±0.006	0.005±0.005	0.000±0.000
<u>Araneae</u>					
Anyphaenidae	0.015±0.007	0.030±0.015	0.015±0.010	0.025±0.014	0.005±0.005
Araneidae	0.265±0.040	0.337±0.072	0.172±0.072	0.182±0.038	0.153±0.035
Clubionidae	0.005±0.005	0.097±0.032	0.025±0.009	0.010±0.006	0.030±0.011
Linyphiidae	0.020±0.015	0.015±0.007	0.025±0.009	0.015±0.010	0.035±0.005
Lycosidae	0.000±0.000	0.010±0.006	0.000±0.000	0.000±0.000	0.005±0.005
Micryphantidae	0.015±0.015	0.035±0.009	0.020±0.010	0.005±0.005	0.020±0.010

Table 5.2. Continued.

Taxon	Treatment				Reference
	Control	ULW [®]	Burn	Felling	
Mimetidae	0.005±0.005	0.010±0.006	0.025±0.009	0.020±0.010	0.010±0.006
Oxyopidae	0.015±0.015	0.035±0.009	0.027±0.027	0.030±0.011	0.035±0.005
Philodromidae	0.005±0.005	0.000±0.000	0.005±0.005	0.015±0.015	0.030±0.019
Pisauridae	0.000±0.000	0.000±0.000	0.010±0.010	0.000±0.000	0.005±0.005
Salticidae	0.112±0.025	0.157±0.057	0.088±0.030	0.127±0.027	0.218±0.077
Tetragnathidae	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Theridiidae	0.010±0.006	0.015±0.007	0.010±0.006	0.005±0.005	0.015±0.007
Thomisidae	0.265±0.148	0.133±0.032	0.232±0.111	0.143±0.043	0.280±0.068
Blattaria					
Blattellidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Coleoptera					
Alleculidae	0.000±0.000	0.005±0.005	0.000±0.000	0.005±0.005	0.000±0.000
Anobiidae	0.010±0.006	0.010±0.006	0.010±0.006	0.005±0.005	0.000±0.000
Anthicidae	0.010±0.006	0.000±0.000	0.005±0.005	0.010±0.010	0.000±0.000
Anthribidae	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.118±0.101
Bruchidae	0.020±0.020	0.010±0.006	0.010±0.010	0.010±0.006	0.005±0.005
Buprestidae	0.005±0.005	0.040±0.018	0.015±0.010	0.052±0.034	0.040±0.013
Cantharidae	0.025±0.020	0.010±0.006	0.032±0.026	0.000±0.000	0.000±0.000
Cerambycidae	0.000±0.000	0.010±0.010	0.005±0.005	0.005±0.005	0.015±0.010
Chrysomelidae	0.118±0.046	0.062±0.026	0.035±0.012	0.062±0.031	0.067±0.025
Alticinae	0.005±0.005	0.015±0.010	0.010±0.010	0.000±0.000	0.057±0.034
Hispininae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.006
Cicindelidae	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.006	0.005±0.005
Cleridae	0.000±0.000	0.005±0.005	0.000±0.000	0.005±0.005	0.000±0.000
Coccinellidae	0.030±0.015	0.062±0.027	0.020±0.013	0.060±0.020	0.030±0.008
Corylophidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Curculionidae	0.035±0.020	0.010±0.006	0.020±0.006	0.025±0.012	0.015±0.015
Apioninae	0.000±0.000	0.005±0.005	0.115±0.109	0.000±0.000	0.063±0.041
Elateridae	0.010±0.010	0.005±0.005	0.025±0.009	0.020±0.015	0.047±0.027
Euglenidae	0.020±0.010	0.010±0.006	0.005±0.005	0.000±0.000	0.000±0.000
Histeridae	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Lathridiidae	0.010±0.006	0.015±0.007	0.000±0.000	0.005±0.005	0.025±0.014
Lycidae	0.000±0.000	0.010±0.006	0.000±0.000	0.037±0.031	0.000±0.000
Scaptiinae	0.010±0.010	0.000±0.000	0.005±0.005	0.020±0.015	0.000±0.000
Melyridae	0.650±0.346	0.423±0.164	0.072±0.056	0.292±0.115	0.015±0.007
Mordellidae	0.183±0.073	0.088±0.038	0.063±0.036	0.157±0.053	0.010±0.010
Mycetophagidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Oedemeridae	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
Phalacridae	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.010±0.006
Platypodidae	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
Scarabaeidae	0.005±0.005	0.000±0.000	0.005±0.005	0.005±0.005	0.005±0.005
Scolytidae	0.005±0.005	0.005±0.005	0.000±0.000	0.000±0.000	0.010±0.010
Tenebrionidae	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Collembola					
Entomobryidae	0.025±0.012	0.005±0.005	0.010±0.010	0.025±0.020	0.010±0.006

Table 5.2. Continued.

Taxon	Treatment				Reference
	Control	ULW [®]	Burn	Felling	
Sminthuridae	0.760±0.499	0.300±0.264	10.893±0.841	0.380±0.100	0.708±0.168
Diptera					
Agromyzidae	0.030±0.015	0.047±0.030	0.015±0.015	0.037±0.025	0.025±0.009
Anthomyiidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Anthomyzidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Asilidae	0.052±0.035	0.103±0.044	0.130±0.060	0.030±0.013	0.047±0.029
Bibionidae	0.000±0.000	0.015±0.015	0.000±0.000	0.000±0.000	0.000±0.000
Bombyliidae	0.005±0.005	0.000±0.000	0.015±0.010	0.000±0.000	0.010±0.006
Angioneurini	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Cecidomyiidae	0.487±0.089	0.708±0.191	0.508±0.148	0.780±0.107	0.395±0.090
Ceratopogonidae	0.035±0.016	0.442±0.424	0.118±0.035	0.067±0.039	0.030±0.020
Chironomidae	0.202±0.095	0.177±0.142	0.162±0.060	0.427±0.153	0.098±0.075
Chloropidae	0.080±0.015	0.118±0.053	0.145±0.041	0.153±0.047	0.332±0.176
Clusiidae	0.015±0.015	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
Culicidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.020±0.020
Dolichopodidae	0.273±0.116	0.140±0.066	0.123±0.045	0.133±0.062	0.103±0.039
Drosophilidae	0.000±0.000	0.005±0.005	0.000±0.000	0.005±0.005	0.000±0.000
Empididae	0.140±0.073	0.105±0.060	0.123±0.057	0.777±0.317	0.010±0.006
Ephydriidae	0.000±0.000	0.000±0.000	0.010±0.010	0.000±0.000	0.000±0.000
Lauxaniidae	0.108±0.022	0.150±0.050	0.070±0.020	0.253±0.163	0.000±0.000
Micropezidae	0.010±0.006	0.000±0.000	0.010±0.006	0.000±0.000	0.005±0.005
Milichiidae	0.010±0.010	0.067±0.040	0.077±0.038	0.060±0.017	0.025±0.009
Muscidae	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
Mycetophilidae	0.025±0.014	0.015±0.007	0.005±0.005	0.005±0.005	0.000±0.000
Otitidae	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
Phoridae	0.322±0.071	0.197±0.038	0.118±0.037	0.265±0.071	0.165±0.071
Pipunculidae	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.005±0.005
Platystomatidae	0.010±0.006	0.000±0.000	0.098±0.092	0.032±0.032	0.025±0.009
Psychodidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Sarcophagidae	0.000±0.000	0.005±0.005	0.005±0.005	0.000±0.000	0.005±0.005
Miltogramminae	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
Scatopsidae	0.000±0.000	0.005±0.005	0.000±0.000	0.005±0.005	0.000±0.000
Sciaridae	0.057±0.023	0.092±0.044	0.055±0.014	0.113±0.035	0.020±0.010
Simuliidae	0.098±0.060	0.092±0.034	0.067±0.030	0.180±0.091	0.182±0.078
Syrphidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Tabanidae	0.005±0.005	0.005±0.005	0.010±0.006	0.042±0.030	0.020±0.010
Tachinidae	0.005±0.005	0.005±0.005	0.010±0.006	0.005±0.005	0.005±0.005
Tephritidae	0.000±0.000	0.010±0.010	0.000±0.000	0.000±0.000	0.000±0.000
Therevidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Tipulidae	0.000±0.000	0.010±0.010	0.015±0.007	0.005±0.005	0.000±0.000
Hemiptera					
Berytidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Coreidae	0.025±0.020	0.045±0.017	0.020±0.010	0.020±0.010	0.030±0.019
Lygaeidae	0.000±0.000	0.000±0.000	0.025±0.016	0.005±0.005	0.015±0.007
Miridae	0.072±0.030	0.042±0.030	0.062±0.027	0.052±0.037	0.128±0.057

Table 5.2. Continued.

Taxon	Treatment				Reference
	Control	ULW [®]	Burn	Felling	
Pentatomidae	0.032±0.026	0.015±0.010	0.005±0.005	0.005±0.005	0.077±0.032
Reduviidae	0.000±0.000	0.020±0.013	0.000±0.000	0.010±0.010	0.025±0.020
Rhopalidae	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Homoptera					
Acanaloniidae	0.010±0.006	0.082±0.027	0.025±0.009	0.025±0.012	0.067±0.031
Aleyrodidae	0.015±0.010	0.015±0.010	0.010±0.010	0.005±0.005	0.113±0.073
Aphididae	0.135±0.051	0.055±0.021	0.343±0.181	0.172±0.057	0.447±0.141
Cercopidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.015±0.010
Cicadellidae	0.693±0.185	0.468±0.132	1.120±0.283	0.632±0.162	1.745±0.188
Cixiidae	0.057±0.030	0.025±0.009	0.118±0.045	0.065±0.018	0.005±0.005
Coccoidea	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Delphacidae	0.000±0.000	0.005±0.005	0.000±0.000	0.025±0.009	0.147±0.064
Derbidae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Dictyopharidae	0.010±0.006	0.000±0.000	0.030±0.015	0.020±0.015	0.072±0.038
Eriosomatidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Flatidae	0.145±0.075	0.238±0.138	0.545±0.267	0.030±0.019	0.285±0.106
Fulgoroidea	0.005±0.005	0.000±0.000	0.005±0.005	0.015±0.010	0.015±0.007
Issidae	0.115±0.041	0.075±0.020	0.030±0.019	0.187±0.085	0.045±0.017
Membracidae	0.010±0.006	0.030±0.019	0.010±0.006	0.000±0.000	0.032±0.026
Psyllidae	0.270±0.107	0.108±0.042	0.057±0.035	0.162±0.109	0.212±0.118
Hymenoptera					
Aphelinidae	0.015±0.010	0.005±0.005	0.000±0.000	0.005±0.005	0.000±0.000
Bethylidae	0.000±0.000	0.005±0.005	0.010±0.010	0.005±0.005	0.010±0.010
Braconidae	0.228±0.062	0.177±0.057	0.208±0.050	0.395±0.076	0.197±0.069
Alysiinae	0.015±0.010	0.020±0.015	0.000±0.000	0.015±0.015	0.000±0.000
Cheloninae	0.005±0.005	0.025±0.016	0.010±0.010	0.005±0.005	0.000±0.000
Ceraphronidae	0.010±0.006	0.010±0.006	0.015±0.010	0.042±0.026	0.015±0.007
Chalcididae	0.005±0.005	0.000±0.000	0.015±0.010	0.000±0.000	0.015±0.007
Chalcidoidea	0.010±0.006	0.010±0.010	0.000±0.000	0.020±0.015	0.030±0.019
Chrysididae	0.005±0.005	0.015±0.010	0.000±0.000	0.000±0.000	0.005±0.005
Colletidae	0.005±0.005	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Crabronidae	0.000±0.000	0.000±0.000	0.020±0.010	0.000±0.000	0.000±0.000
Cynipidae	0.030±0.011	0.020±0.015	0.042±0.026	0.057±0.027	0.077±0.033
Diapriidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Belytinae	0.005±0.005	0.010±0.010	0.000±0.000	0.020±0.020	0.000±0.000
Dryinidae	0.005±0.005	0.010±0.010	0.000±0.000	0.005±0.005	0.010±0.010
Elasmidae	0.020±0.010	0.000±0.000	0.005±0.005	0.000±0.000	0.010±0.010
Encyrtidae	0.130±0.043	0.100±0.029	0.050±0.018	0.103±0.064	0.082±0.049
Eucharitidae	0.005±0.005	0.010±0.006	0.010±0.006	0.015±0.015	0.010±0.006
Eucoilidae	0.025±0.020	0.045±0.017	0.005±0.005	0.015±0.010	0.005±0.005
Eulophidae	0.317±0.064	0.355±0.111	0.298±0.125	0.377±0.115	0.442±0.159
Euderinae	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Eupelmidae	0.005±0.005	0.005±0.005	0.005±0.005	0.005±0.005	0.010±0.006
Eurytomidae	0.015±0.010	0.015±0.010	0.035±0.020	0.057±0.036	0.072±0.030
Evaniidae	0.005±0.005	0.010±0.006	0.000±0.000	0.000±0.000	0.000±0.000

Table 5.2. Continued.

Taxon	Treatment				Reference
	Control	ULW [®]	Burn	Felling	
Formicidae	1.035±0.103	0.967±0.315	0.958±0.394	0.817±0.159	0.578±0.120
Halictidae	0.015±0.007	0.015±0.010	0.035±0.020	0.000±0.000	0.015±0.007
Ichneumonidae	0.015±0.007	0.035±0.014	0.010±0.006	0.015±0.007	0.005±0.005
Megachilidae	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
Mutillidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.010
Mymaridae	0.078±0.045	0.025±0.009	0.113±0.051	0.040±0.013	0.088±0.038
Ormyridae	0.005±0.005	0.005±0.005	0.000±0.000	0.005±0.005	0.000±0.000
Perilampidae	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Platygastridae	0.272±0.073	0.460±0.212	0.250±0.030	0.287±0.109	0.175±0.068
Pompilidae	0.005±0.005	0.015±0.007	0.000±0.000	0.000±0.000	0.010±0.006
Pteromalidae	0.077±0.018	0.035±0.009	0.042±0.024	0.062±0.029	0.020±0.010
Cleonyminae	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Scelionidae	0.035±0.012	0.082±0.031	0.063±0.031	0.040±0.018	0.062±0.044
Symphyta	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.057±0.057
Tenthredinidae	0.140±0.068	0.642±0.505	0.138±0.086	0.198±0.080	0.005±0.005
Tiphiidae	0.005±0.005	0.000±0.000	0.005±0.005	0.005±0.005	0.005±0.005
Torymidae	0.035±0.014	0.045±0.019	0.020±0.015	0.020±0.015	0.057±0.033
Trichogrammatidae	0.000±0.000	0.015±0.010	0.000±0.000	0.010±0.006	0.020±0.006
<u>Isoptera</u>					
Rhinotermitidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.015±0.015
<u>Lepidoptera</u>					
Arctiidae	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Geometridae	0.088±0.047	0.098±0.040	0.187±0.082	0.125±0.038	0.218±0.102
Noctuidae	0.005±0.005	0.000±0.000	0.005±0.005	0.005±0.005	0.000±0.000
Psychidae	0.010±0.006	0.015±0.010	0.005±0.005	0.005±0.005	0.035±0.020
<u>Mantodea</u>					
Mantidae	0.000±0.000	0.005±0.005	0.005±0.005	0.000±0.000	0.005±0.005
<u>Neuroptera</u>					
Ascalaphidae	0.005±0.005	0.005±0.005	0.000±0.000	0.000±0.000	0.032±0.032
Berothidae	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Chrysopidae	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
Coniopterygidae	0.005±0.005	0.010±0.006	0.020±0.010	0.000±0.000	0.005±0.005
Hemerobiidae	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
Myrmeliontidae	0.005±0.005	0.000±0.000	0.010±0.006	0.005±0.005	0.020±0.015
<u>Odonata</u>					
Zygoptera	0.000±0.000	0.000±0.000	0.010±0.006	0.005±0.005	0.032±0.032
<u>Orthoptera</u>					
Acrididae	0.660±0.159	0.683±0.165	10.527±0.265	0.797±0.200	0.828±0.121
Gryllacrididae	0.000±0.000	0.005±0.005	0.005±0.005	0.000±0.000	0.000±0.000
Gryllidae	0.070±0.017	0.140±0.043	0.078±0.037	0.137±0.036	0.083±0.041
Tettigoniidae	0.180±0.043	0.160±0.044	0.447±0.097	0.238±0.100	0.238±0.035
<u>Phasmida</u>					
Pseudophasmatidae	0.000±0.000	0.010±0.010	0.000±0.000	0.025±0.009	0.000±0.000
<u>Psocoptera</u>					
Lepidopsocidae	0.010±0.010	0.000±0.000	0.005±0.005	0.005±0.005	0.000±0.000

Table 5.2. Continued.

Taxon	Treatment				Reference
	Control	ULW®	Burn	Felling	
Psocidae	0.057±0.033	0.302±0.166	0.052±0.035	0.055±0.025	0.047±0.024
<u>Thysanoptera</u>					
Phlaeothripidae	0.005±0.005	0.037±0.025	0.040±0.017	0.047±0.026	0.010±0.006

Table 5.3. Two-way analyses of covariance for tests of restoration treatments and pre-treatment effects on arthropod morpho/species densities from the spring 1996 sampling period in mixed hardwoods and longleaf pine forests at Eglin Air Force Base, Florida. Restoration treatments are growing season burn, application of ULW[®] herbicide, hand felling and girdling of hardwoods and sand pine, and no-treatment control. The experimental design is a complete randomized block, split-plot design, but only the block design at the whole plot level is presented here. The covariate is the spring 1995 pre-treatment data. The error term is the mean square of the interaction of the block and restoration effects. Significance probabilities and sum of squares were calculated by a computer randomization ANCOVA based on 10,000 permutations. Calculations and tests followed Steel and Torrie (1980: 411-419, 215-217, 260). Arthropod densities were $\sqrt{(X + 0.5)}$ transformed to stabilize variances.

Source	Sum of Squares	t-value	df	p-value
Coleoptera				
<i>Altica</i> sp.				
Block	0.0016		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Apion</i> sp.				
Block	0.1930		5	
Restoration	0.1034		3	0.1798
Pre-treatment	0.0001		1	0.5000
Error	0.6910		14	
<i>Attalus circumscriptus</i>				
Block	0.0864		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Attalus</i> sp.				
Block	5.2274		5	
Restoration	1.7468		3	0.2670
Pre-treatment	0.0429		1	0.5000
Error	5.0581		14	
<i>Brachiacantha decempustulata</i>				
Block	0.0790		5	
Restoration	0.0165		3	0.5507
Pre-treatment	0.0023		1	0.5000
Error	0.1661		14	
<i>Exochomus marginipennis</i>				
Block	0.0065		5	
Restoration	0.0000		3	0.9999
Error	0.0035		15	
<i>Metachroma pellucidum</i>				
Block	0.0208		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Pachybrachis</i> spp.				
Block	0.0068		5	
Restoration	0.0045		3	0.9999
Error	0.0097		15	

Table 5.3. Continued.

Source	Sum of squares	t-value	df	p-value
<i>Triachus atomus</i>				
Block	0.1613		5	
Restoration	0.0540		3	0.7638
Pre-treatment	0.0019		1	0.5000
Error	0.3517		14	
<i>Trigonorhinus rotundatus</i>				
Block	0.0016		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Scymnus (Scymnus) sp.</i>				
Block	0.0029		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<u>Collembola</u>				
<i>Entomobrya assuta</i>				
Block	0.0026		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
Entomobryidae undetermined #4				
Block	0.0029		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Salina banksi</i>				
Block	0.0065		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Sminthurus carolinensis</i>				
Block	16.9353		5	
Restoration	10.5873		3	0.0018
Pre-treatment	0.8870		1	0.5000
Error	18.9238		14	
Contrast				
C vs B†		-0.8418	1	0.0000
B vs F/G		0.6247	1	0.0000
B vs U		0.8729	1	0.0001
<u>Diptera</u>				
<i>Conioscinella grisescens</i>				
Block	0.1147		5	
Restoration	0.1098		3	0.2584
Pre-treatment	0.0637		1	0.0050
Error	0.0972		14	
Chloropidae undetermined #6				
Block	0.0279		5	
Restoration	0.0681		3	0.2982
Pre-treatment	0.0072		1	0.5000
Error	0.1089		14	

† Abbreviations of treatments: B = burn; C = control; F/G = felling/girdling; U = ULW®.

Table 5.3. Continued.

Source	Sum of squares	t-value	df	p-value
<i>Chloropidae</i> undetermined #7				
Block	0.0016		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Empididae</i> undetermined #1				
Block	4.1645		5	
Restoration	3.9585		3	0.0094
Pre-treatment	0.1219		1	0.5000
Error	2.6652		14	
Contrast				
C vs B		-0.2790	1	0.1009
B vs F/G		-1.3086	1	0.0000
B vs U		-0.0029	1	0.2339
<i>Euhybus</i> sp.				
Block	0.0016		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Hippelates</i> sp.				
Block	0.3385		5	
Restoration	0.0391		3	0.6735
Pre-treatment	0.0000		1	0.5000
Error	0.1355		14	
<i>Holopogon</i> sp.				
Block	0.768		5	
Restoration	0.1945		3	0.4281
Pre-treatment	0.0086		1	0.5000
Error	0.3306		14	
<i>Melanomyza</i> sp.				
Block	1.4586		5	
Restoration	0.4099		3	0.0573
Pre-treatment	0.0002		1	0.5000
Error	1.5714		14	
<i>Milichiidae</i> undetermined #4				
Block	0.0244		5	
Restoration	0.0106		3	0.4673
Pre-treatment	0.0006		1	0.5000
Error	0.0303		14	
<i>Pholeomyia</i> sp.				
Block	0.2029		5	
Restoration	0.1132		3	0.3676
Pre-treatment	0.0196		1	0.5000
Error	0.3139		14	
<i>Poecilominettia valida</i>				
Block	0.0260		5	
Restoration	0.0043		3	0.9403
Pre-treatment	0.0012		1	0.5000
Error	0.0613		14	
<i>Rivellia metallica</i>				
Block	0.2894		5	

Table 5.3. Continued.

Source	Sum of squares	t-value	df	p-value
Restoration	0.0000		3	0.9999
Error	0.0000		14	
<i>Stichopogon</i> sp.				
Block	0.0029		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<u>Homoptera</u>				
<i>Acanalonia latifrons</i>				
Block	0.0565		5	
Restoration	0.0859		3	0.0831
Pre-treatment	0.0044		1	0.5000
Error	0.1371		14	
<i>Bruchomorpha minima</i>				
Block	0.0234		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
Cicadellidae undetermined #25				
Block	0.0937		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
Cicadellidae undetermined #27				
Block	0.0156		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
Cicadellidae undetermined #28				
Block	0.8560		5	
Restoration	0.1825		3	0.0718
Pre-treatment	0.2228		1	0.0025
Error	0.2339		14	
Cicadellidae undetermined #32				
Block	0.0143		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
Cicadellidae undetermined #33				
Block	0.0065		5	
Restoration	0.0000		3	0.9999
Error	0.0017		15	
Delphacidae undetermined #3				
Block	0.0016		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
Delphacidae undetermined #6				
Block	0.0016		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
Dictyopharidae undetermined #2				
Block	0.0876		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	

Table 5.3. Continued.

Source	Sum of squares	t-value	d f	p-value
<i>Draeculocephala septemguttata</i>				
Block	0.0065		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Empoasca</i> spp.				
Block	0.0146		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Erythroneura</i> spp.				
Block	0.2557		5	
Restoration	0.1659		3	0.0210
Pre-treatment	0.0331		1	0.2000
Error	0.2615		14	
Contrast				
C vs B		-0.5962	1	0.0046
B vs F/G		-0.3706	1	0.0294
B vs U		0.3937	1	0.0785
<i>Eutettix tristis</i>				
Block	0.1969		5	
Restoration	0.0079		3	0.9263
Pre-treatment	0.0003		1	0.5000
Error	0.0437		14	
<i>Hysteropterus punctiferum</i>				
Block	0.4113		5	
Restoration	0.1190		3	0.1060
Pre-treatment	0.4206		1	0.0050
Error	0.5976		14	
<i>Metcalfa pruinosa</i>				
Block	3.8431		5	
Restoration	1.6824		3	0.0258
Pre-treatment	0.1147		1	0.5000
Error	3.9274		14	
Contrast				
C vs B		-0.4094	1	0.0002
B vs F/G		0.8515	1	0.0000
B vs U		0.5620	1	0.0050
<i>Oecleus</i> sp.				
Block	0.2911		5	
Restoration	0.1094		3	0.6707
Pre-treatment	0.0016		1	0.5000
Error	0.3222		14	
<i>Oliarus vicarius</i>				
Block	0.0172		5	
Restoration	0.0115		3	0.7630
Pre-treatment	0.0100		1	0.0005
Error	0.0230		14	
<i>Paraphlepsius mimus</i> (?)				
Block	0.0156		5	
Restoration	0.0014		3	0.9999

Table 5.3. Continued.

Source	Sum of squares	t-value	df	p-value
Pre-treatment	0.0001		1	0.5000
Error	0.0181		14	
<i>Penthimia</i> sp.				
Block	0.0016		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Rugosana querci</i>				
Block	0.0016		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Scaphoideus</i> sp.				
Block	0.0092		5	
Restoration	0.0065		3	0.8638
Pre-treatment	0.0003		1	0.9999
Error	0.0208		14	
<i>Scaphytopius rubillus</i> (?)				
Block	0.2566		5	
Restoration	0.0921		3	0.3195
Pre-treatment	0.0716		1	0.1000
Error	0.2450		14	
Hymenoptera				
<i>Aspilota</i> sp.				
Block	0.0143		5	
Restoration	0.0000		3	0.9999
Error	0.0000		14	
<i>Brachymyrmex depilis</i>				
Block	0.1748		5	
Restoration	0.0278		3	0.5259
Pre-treatment	0.0015		1	0.5000
Error	0.3484		14	
<i>Camponotus socius</i>				
Block	0.0068		5	
Restoration	0.0000		3	0.9999
Error	0.0000		14	
<i>Chelonus</i> sp.				
Block	0.6940		5	
Restoration	0.0631		3	0.9199
Pre-treatment	0.0110		1	0.5000
Error	0.6015		14	
<i>Crematogaster ashmeadi</i>				
Block	1.6006		5	
Restoration	0.3459		3	0.2247
Pre-treatment	0.1000		1	0.5000
Error	1.4084		14	
<i>Dolichoderus pustulatus</i>				
Block	0.0752		5	
Restoration	0.0118		3	0.4295
Pre-treatment	0.0681		1	0.0025
Error	0.0672		14	

Table 5.3. Continued.

Source	Sum of squares	t-value	df	p-value
<i>Forelius pruinus</i>				
Block	0.8464		5	
Restoration	0.1442		3	0.9433
Pre-treatment	0.1129		1	0.5000
Error	1.2002		14	
<i>Formica pallidefulva</i>				
Block	0.0012		5	
Restoration	0.0007		3	0.9048
Pre-treatment	0.0004		1	0.9999
Error	0.0034		14	
<i>Formica schaufussi</i>				
Block	0.0339		5	
Restoration	0.0000		3	0.9999
Error	0.0000		14	
<i>Heterospilus</i> sp.				
Block	0.1504		5	
Restoration	0.1589		3	0.0971
Pre-treatment	0.0147		1	0.2000
Error	0.1071		14	
<i>Leptothorax pergandei</i>				
Block	0.1060		5	
Restoration	0.0679		3	0.2259
Pre-treatment	0.0000		1	0.5000
Error	0.2671		14	
<i>Leptothorax texanus</i>				
Block	0.2168		5	
Restoration	0.0664		3	0.9760
Pre-treatment	0.0184		1	0.5000
Error	0.5081		14	
<i>Monomorium viride</i>				
Block	0.2664		5	
Restoration	0.0441		3	0.6848
Pre-treatment	0.0507		1	0.5000
Error	0.7187		14	
<i>Oreasema</i> nr. <i>bakeri</i>				
Block	0.0378		5	
Restoration	0.0014		3	0.9926
Pre-treatment	0.0014		1	0.5000
Error	0.0468		14	
<i>Paratrechina wojciki</i>				
Block	0.1219		5	
Restoration	0.0330		3	0.7371
Pre-treatment	0.0061		1	0.5000
Error	0.5721		14	
<i>Pheidole adrianoi</i>				
Block	0.1055		5	
Restoration	0.0100		3	0.9999
Pre-treatment	0.0211		1	0.2000
Error	0.1365		14	

Table 5.3. Continued.

Source	Sum of squares	t-value	df	p-value
<i>Pheidole dentata</i>				
Block	0.0120		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Pheidole floridana</i>				
Block	0.0285		5	
Restoration	0.0300		3	0.6090
Pre-treatment	0.0079		1	0.5000
Error	0.2280		14	
<i>Pseudomyrmex ejectus</i>				
Block	0.0146		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Pseudomyrmex pallidus</i>				
Block	0.0401		5	
Restoration	0.0126		3	0.6556
Pre-treatment	0.0343		1	0.0500
Error	0.0772		14	
<i>Solenopsis abdita</i>				
Block	0.0016		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Solenopsis picta</i>				
Block	0.0026		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Trachymyrmex septentrionalis</i>				
Block	0.3996		5	
Restoration	0.4483		3	0.0001
Pre-treatment	0.2302		1	0.1000
Error	1.0011		14	
Contrast				
C vs B		0.0478	1	0.5478
B vs F/G		0.0675	1	0.0035
B vs U		-0.9673	1	0.0000
<u>Araneae</u>				
<i>Acacesia hamata</i>				
Block	0.0117		5	
Pre-treatment	0.0000		1	0.9999
Error	0.0000		15	
<i>Acanthepeira stellata</i>				
Block	0.0273		5	
Restoration	0.0042		3	0.9154
Pre-treatment	0.0002		1	0.5000
Error	0.0505		14	
<i>Araneus</i> sp.				
Block	0.0016		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	

Table 5.3. Continued.

Source	Sum of squares	t-value	df	p-value
<i>Eustala</i> sp.				
Block	0.1675		5	
Restoration	0.1115		3	0.5225
Pre-treatment	0.0163		1	0.5000
Error	0.5534		14	
<i>Mangora gibberosa</i>				
Block	0.1723		5	
Restoration	0.1151		3	0.3282
Pre-treatment	0.0001		1	0.5000
Error	0.2601		14	
<i>Mimetus</i> sp.				
Block	0.0312		5	
Restoration	0.0127		3	0.2717
Pre-treatment	0.0001		1	0.5000
Error	0.0338		14	
<i>Habronattus</i> sp.				
Block	0.0273		5	
Restoration	0.0011		3	0.9544
Pre-treatment	0.0001		1	0.5000
Error	0.0221		14	
<i>Hamataliwa</i> sp.				
Block	0.0016		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Hentzia</i> sp.				
Block	0.0055		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Maevia</i> sp.				
Block	0.0065		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Misumenoides formosipes</i>				
Block	0.1471		5	
Restoration	0.0035		3	0.9998
Pre-treatment	0.0028		1	0.5000
Error	0.1209		14	
<i>Misumenops</i> sp.				
Block	0.2435		5	
Restoration	0.0033		3	0.9999
Pre-treatment	0.0001		1	0.5000
Error	0.0494		14	
<i>Oxyopes</i> sp.				
Block	0.0068		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Peucetia viridans</i>				
Block	0.0715		5	
Restoration	0.0026		3	0.9488

Table 5.3. Continued.

Source	Sum of squares	t-value	df	p-value
Pre-treatment	0.0005		1	0.5000
Error	0.1328		14	
<i>Tibellus oblongus</i>				
Block	0.0173		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	
<i>Tmarus</i> sp.				
Block	1.4427		5	
Restoration	0.1522		3	0.7737
Pre-treatment	0.3178		1	0.0250
Error	0.5957		14	
<i>Xysticus</i> sp.				
Block	0.1592		5	
Restoration	0.0278		3	0.5436
Pre-treatment	0.0120		1	0.5000
Error	0.1843		14	
<i>Zygoballus</i> sp.				
Block	0.0171		5	
Restoration	0.0000		3	0.9999
Error	0.0000		15	

Table 5.4. Mean (± 1 standard error) of arthropod morpho/species densities (individuals/4m²) per 81-ha (200-acre) restoration treatments and reference plots at Eglin Air Force Base, Florida. Sample size = 6 blocks.

Species/Morphospecies	Treatment				Reference
	Control	ULW ^a	Burn	Felling	
Spring 1995					
<u>Coleoptera</u>					
<i>Altica</i> spp.	0.000±0.000	0.005±0.005	0.005±0.005	0.005±0.005	0.042±0.042
<i>Anisostena nigrita</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Apion</i> sp.	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.010	0.042±0.036
<i>Attalus circumscriptus</i> Say	0.000±0.000	0.026±0.015	0.026±0.017	0.016±0.016	0.026±0.020
<i>Attalus</i> sp.	0.214±0.050	0.021±0.015	0.037±0.031	0.245±0.125	0.021±0.013
<i>Brachiacantha decempustulata</i>	0.052±0.031	0.052±0.034	0.026±0.010	0.036±0.012	0.005±0.005
<i>Diomus debilis</i>	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Diomus terminatus</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Exochomus marginipennis</i>	0.000±0.000	0.005±0.005	0.010±0.007	0.005±0.005	0.016±0.007
<i>Hemisphaerota cyanea</i>	0.010±0.007	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
<i>Longitarsus testaceus</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.042±0.042
<i>Metachroma pellucidum</i>	0.005±0.005	0.000±0.000	0.010±0.010	0.016±0.016	0.021±0.010
<i>Metachroma quercatum</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.021±0.021
<i>Oulema cornuta</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Pachybrachis</i> spp.	0.005±0.005	0.010±0.007	0.010±0.007	0.005±0.005	0.005±0.005
<i>Psyllobora parvinotata</i>	0.000±0.000	0.010±0.010	0.000±0.000	0.000±0.000	0.005±0.005
<i>Scymnus cervicalis</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Scymnus</i> (<i>Scymnus</i>) sp.	0.010±0.007	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
<i>Triachus atomus</i>	0.010±0.007	0.031±0.016	0.016±0.011	0.021±0.015	0.016±0.016
<i>Trigonorhinus rotundatus</i>	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.099±0.037
<u>Collembola</u>					
<i>Entomobrya assuta</i>	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Entomobryidae undetermined #4	0.000±0.000	0.010±0.010	0.010±0.007	0.010±0.007	0.016±0.007
<i>Orchesella</i> sp.	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Salina banksi</i>	0.026±0.012	0.042±0.015	0.031±0.020	0.042±0.022	0.109±0.042
<i>Sminthurus carolinensis</i>	0.219±0.146	0.219±0.093	0.349±0.097	0.083±0.050	0.526±0.299
<i>Sminthurus floridanus</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.063±0.063
<u>Diptera</u>					
<i>Ceratobarys eulophus</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
Chloropidae undetermined #3	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.021±0.010
Chloropidae undetermined #6	0.052±0.041	0.005±0.005	0.005±0.005	0.010±0.007	0.000±0.000
Chloropidae undetermined #7	0.000±0.000	0.005±0.005	0.010±0.007	0.000±0.000	0.010±0.007
<i>Conioscinella grisescens</i>	0.078±0.027	0.047±0.019	0.062±0.027	0.026±0.010	0.172±0.043
Empididae undetermined #1	0.870±0.198	0.010±0.010	0.125±0.113	0.104±0.064	0.115±0.065
<i>Euhybus</i> sp.	0.005±0.005	0.031±0.020	0.010±0.010	0.000±0.000	0.005±0.005
<i>Hippelates</i> sp.	0.016±0.011	0.078±0.072	0.016±0.016	0.036±0.015	0.292±0.125
<i>Holopogon</i> sp.	0.005±0.005	0.026±0.017	0.042±0.019	0.042±0.022	0.000±0.000
<i>Melanomyza</i> sp.	0.047±0.024	0.094±0.038	0.271±0.169	0.146±0.057	0.000±0.000
Milichiidae undetermined #4	0.062±0.012	0.005±0.005	0.016±0.011	0.000±0.000	0.016±0.016
<i>Phleomyia</i> sp.	0.010±0.007	0.005±0.005	0.016±0.007	0.000±0.000	0.000±0.000
<i>Platypalpus</i> sp.	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.010
<i>Poecilominettia valida</i>	0.010±0.010	0.021±0.013	0.036±0.012	0.016±0.011	0.005±0.005
<i>Rivellia metallica</i>	0.037±0.037	0.000±0.000	0.037±0.037	0.000±0.000	0.182±0.110
<i>Stichopogon</i> sp.	0.010±0.007	0.000±0.000	0.000±0.000	0.005±0.005	0.005±0.005
<i>Trichina</i> sp.	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005

Table 5.4. Continued.

Species/Morphospecies	Treatment				Reference
	Control	ULW®	Bum	Felling	
Homoptera					
<i>Acanalonia latifrons</i>	0.021±0.010	0.052±0.025	0.047±0.013	0.031±0.011	0.083±0.044
<i>Balclutha guajanae</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
<i>Bruchomorpha minima</i>	0.010±0.007	0.000±0.000	0.000±0.000	0.005±0.005	0.042±0.026
<i>Cedusa</i> sp.	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.010±0.010
Cicadellidae undetermined #25	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.026±0.017
Cicadellidae undetermined #27	0.000±0.000	0.010±0.010	0.005±0.005	0.010±0.007	0.000±0.000
Cicadellidae undetermined #28	0.083±0.026	0.000±0.000	0.026±0.026	0.000±0.000	0.203±0.102
Cicadellidae undetermined #31	0.010±0.007	0.005±0.005	0.005±0.005	0.021±0.010	0.010±0.007
Cicadellidae undetermined #32	0.005±0.005	0.000±0.000	0.005±0.005	0.000±0.000	0.010±0.007
Cicadellidae undetermined #33	0.010±0.010	0.000±0.000	0.000±0.000	0.000±0.000	0.016±0.016
Cicadellidae undetermined #35	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Cicadellidae undetermined #37	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Cicadellidae undetermined #41	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Cicadellidae undetermined #42	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Delphacidae undetermined #3	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.021±0.021
Delphacidae undetermined #4	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.021±0.021
Delphacidae undetermined #6	0.000±0.000	0.010±0.007	0.000±0.000	0.000±0.000	0.000±0.000
Delphacidae undetermined #7	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Delphacidae undetermined #8	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.026±0.026
Dictyopharidae undetermined #2	0.010±0.007	0.000±0.000	0.005±0.005	0.010±0.010	0.057±0.041
<i>Draeculocephala septemguttata</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.010	0.062±0.031
<i>Empoasca</i> spp.	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.007
<i>Erythroneura</i> spp.	0.078±0.021	0.031±0.011	0.057±0.022	0.057±0.015	0.172±0.064
<i>Eutettix tristis</i>	0.010±0.007	0.000±0.000	0.005±0.005	0.000±0.000	0.068±0.023
<i>Hysteropteris punctiferum</i>	0.083±0.016	0.109±0.043	0.073±0.024	0.136±0.049	0.141±0.041
<i>Liburnella ornata</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Metcalfa pruinosa</i>	0.260±0.091	0.042±0.030	0.099±0.051	0.115±0.086	0.755±0.424
<i>Oecleus</i> sp.	0.010±0.010	0.078±0.031	0.099±0.032	0.042±0.013	0.057±0.041
<i>Oliarus vicarius</i>	0.000±0.000	0.057±0.046	0.005±0.005	0.016±0.007	0.005±0.005
<i>Paraphlepsius mimus</i> (?)	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.031±0.031
<i>Penthimia</i> sp.	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
<i>Polana quadrinotata</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
<i>Rhyncomitra lingula</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.010
<i>Rugosana querci</i>	0.010±0.010	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.007
<i>Scaphoideus</i> sp.	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
<i>Scaphytopius rubillus</i> (?)	0.010±0.007	0.037±0.019	0.010±0.007	0.021±0.013	0.068±0.056
Hymenoptera					
<i>Aspilota</i> sp.	0.021±0.015	0.026±0.017	0.021±0.015	0.026±0.015	0.005±0.005
<i>Brachymyrmex depilis</i>	0.047±0.024	0.021±0.010	0.042±0.022	0.005±0.005	0.083±0.025
<i>Brachymyrmex musculus</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.007
<i>Camponotus socius</i>	0.005±0.005	0.005±0.005	0.005±0.005	0.000±0.000	0.042±0.030
<i>Chelonus</i> sp.	0.021±0.010	0.000±0.000	0.000±0.000	0.010±0.010	0.005±0.005
<i>Crematogaster ashmeadi</i>	0.432±0.241	0.312±0.095	0.365±0.082	0.323±0.095	0.161±0.045
<i>Dolichoderus pustulatus</i>	0.042±0.019	0.005±0.005	0.016±0.011	0.016±0.016	0.031±0.016
<i>Forelius pruinosis</i>	0.073±0.031	0.120±0.052	0.068±0.027	0.146±0.070	0.031±0.020
<i>Formica pallidefulva</i>	0.000±0.000	0.016±0.007	0.005±0.005	0.021±0.010	0.016±0.016
<i>Formica schaufussi</i>	0.005±0.005	0.026±0.012	0.005±0.005	0.010±0.007	0.000±0.000

Table 5.4. Continued.

Species/Morphospecies	Treatment				Reference
	Control	ULW®	Burn	Felling	
<i>Heterospilus</i> sp.	0.083±0.034	0.047±0.019	0.057±0.019	0.047±0.013	0.052±0.021
<i>Leptothorax pergandei</i>	0.057±0.025	0.010±0.007	0.031±0.014	0.104±0.038	0.042±0.017
<i>Leptothorax texanus</i>	0.042±0.015	0.057±0.017	0.016±0.016	0.021±0.007	0.026±0.017
<i>Monomorium viride</i>	0.187±0.080	0.036±0.012	0.031±0.008	0.140±0.060	0.068±0.032
<i>Orasema</i> nr. <i>bakeri</i>	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.036±0.025
<i>Paratrechina wojciki</i>	0.062±0.012	0.120±0.045	0.083±0.034	0.104±0.038	0.057±0.041
<i>Phanerotoma</i> sp.	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
<i>Pheidole adrianoi</i>	0.000±0.000	0.005±0.005	0.000±0.000	0.005±0.005	0.042±0.025
<i>Pheidole dentata</i>	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005
<i>Pheidole floridana</i>	0.042±0.026	0.245±0.106	0.130±0.010	0.120±0.048	0.177±0.057
<i>Prenolepis imparis</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
<i>Pseudomyrmex ejectus</i>	0.005±0.005	0.000±0.000	0.005±0.005	0.005±0.005	0.005±0.005
<i>Pseudomyrmex pallidus</i>	0.052±0.017	0.063±0.063	0.031±0.016	0.031±0.016	0.016±0.011
<i>Solenopsis abdita</i>	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
<i>Solenopsis picta</i>	0.000±0.000	0.021±0.021	0.000±0.000	0.005±0.005	0.016±0.011
<i>Trachymyrmex septentrionalis</i>	0.000±0.000	0.016±0.007	0.000±0.000	0.000±0.000	0.000±0.000
Araneae					
<i>Acacesia hamata</i>	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Acanthepeira stellata</i>	0.016±0.011	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005
<i>Araneus</i> sp.	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
<i>Eustala</i> sp.	0.036±0.015	0.026±0.012	0.016±0.011	0.016±0.011	0.021±0.010
<i>Gea heptagon</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Habronattus</i> sp.	0.005±0.005	0.010±0.007	0.031±0.016	0.005±0.005	0.000±0.000
<i>Hamataliwa</i> sp.	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Hentzia</i> sp.	0.031±0.020	0.026±0.010	0.016±0.016	0.016±0.011	0.010±0.007
<i>Larinia</i> sp.	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Maevia</i> sp.	0.010±0.010	0.000±0.000	0.005±0.005	0.005±0.005	0.000±0.000
<i>Mangora gibberosa</i>	0.021±0.007	0.021±0.013	0.010±0.007	0.010±0.007	0.094±0.029
<i>Marpissa</i> sp.	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Mimetus</i> sp.	0.036±0.015	0.016±0.007	0.026±0.015	0.021±0.010	0.016±0.007
<i>Misumenoides formosipes</i>	0.031±0.011	0.010±0.007	0.005±0.005	0.010±0.007	0.110±0.068
<i>Misumenops</i> sp.	0.141±0.092	0.000±0.000	0.005±0.005	0.000±0.000	0.115±0.051
<i>Oxyopes</i> sp.	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.021±0.010
<i>Peucetia viridans</i>	0.021±0.007	0.010±0.007	0.000±0.000	0.016±0.011	0.057±0.019
<i>Sarinda</i> sp.	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Tibellus oblongus</i>	0.000±0.000	0.005±0.005	0.000±0.000	0.005±0.005	0.026±0.015
<i>Tmarus</i> sp.	0.156±0.056	0.010±0.010	0.031±0.011	0.047±0.041	0.036±0.015
<i>Xysticus</i> sp.	0.115±0.034	0.057±0.019	0.068±0.030	0.073±0.028	0.078±0.030
<i>Zygoballus</i> sp.	0.010±0.010	0.005±0.005	0.000±0.000	0.010±0.010	0.037±0.019
Spring 1996					
Coleoptera					
<i>Altica</i> spp.	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005
<i>Anisostena nigrita</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.007
<i>Apion</i> sp.	0.010±0.010	0.005±0.005	0.104±0.104	0.005±0.005	0.068±0.039
<i>Attalus circumscriptus</i>	0.005±0.005	0.042±0.031	0.000±0.000	0.005±0.005	0.000±0.000
<i>Attalus</i> sp.	0.635±0.349	0.380±0.179	0.073±0.056	0.281±0.119	0.010±0.007
<i>Attalus</i> sp. #2	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Brachiacantha decempustulata</i>	0.031±0.016	0.042±0.025	0.016±0.011	0.036±0.013	0.016±0.007

Table 5.4. Continued.

Species/Morphospecies	Treatment				Reference
	Control	ULW ^a	Burn	Felling	
<i>Collops</i> sp.	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
<i>Diomus debilis</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
<i>Diomus terminatus</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
<i>Exochomus marginipennis</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.010	0.000±0.000
<i>Hemisphaerota cyanea</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
<i>Longitarsus</i> sp.	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
<i>Longitarsus testaceus</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.047±0.035
<i>Metachroma pellucidum</i>	0.036±0.025	0.005±0.005	0.010±0.010	0.000±0.000	0.005±0.005
<i>Metachroma quercatum</i>	0.010±0.007	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Oulema cornuta</i>	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Pachybrachis</i> spp.	0.000±0.000	0.026±0.010	0.010±0.007	0.010±0.007	0.047±0.022
<i>Psyllobora parvnotata</i>	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
<i>Scymnus</i> (<i>Scymnus</i>) sp.	0.000±0.000	0.010±0.007	0.000±0.000	0.005±0.005	0.005±0.005
<i>Scymnus cervicalis</i>	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005
<i>Triachus atomus</i>	0.073±0.044	0.036±0.019	0.026±0.010	0.052±0.029	0.016±0.016
<i>Trigonorhinus rotundatus</i>	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.120±0.102
Collembola					
<i>Entomobrya assuta</i>	0.010±0.007	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
Entomobryidae undetermined #4	0.010±0.007	0.000±0.000	0.005±0.005	0.005±0.005	0.000±0.000
<i>Orchesella</i> sp.	0.000±0.000	0.000±0.000	0.005±0.005	0.016±0.016	0.000±0.000
<i>Salina banksi</i>	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005	0.010±0.007
<i>Sminthurus carolinensis</i>	0.745±0.502	0.250±0.219	1.812±0.804	0.359±0.102	0.646±0.152
<i>Sminthurus floridanus</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Diptera					
<i>Ceratobarys eulophus</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Chloropidae undetermined #3	0.000±0.000	0.010±0.007	0.000±0.000	0.005±0.005	0.026±0.012
Chloropidae undetermined #6	0.010±0.007	0.078±0.030	0.010±0.007	0.021±0.007	0.021±0.015
Chloropidae undetermined #7	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
<i>Conioscinella grisescens</i>	0.057±0.019	0.016±0.011	0.089±0.017	0.078±0.029	0.057±0.034
Empididae undetermined #1	0.130±0.076	0.115±0.069	0.120±0.059	0.766±0.317	0.000±0.000
Empididae undetermined #3	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000
Empididae undetermined #4	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.007
<i>Hippelates</i> sp.	0.016±0.011	0.021±0.021	0.052±0.034	0.042±0.019	0.224±0.134
<i>Holopogon</i> sp.	0.047±0.036	0.104±0.044	0.120±0.058	0.031±0.014	0.042±0.030
<i>Melanomyza</i> sp.	0.094±0.028	0.141±0.053	0.052±0.021	0.250±0.170	0.000±0.000
Milichiidae undetermined #4	0.005±0.005	0.005±0.005	0.005±0.005	0.026±0.015	0.016±0.011
<i>Pholeomyia</i> sp.	0.005±0.005	0.063±0.035	0.068±0.034	0.036±0.015	0.010±0.007
<i>Platypalpus</i> sp.	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
<i>Poecilolycia</i> sp.	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
<i>Poecilominettia valida</i>	0.016±0.016	0.005±0.005	0.016±0.007	0.016±0.007	0.000±0.000
<i>Rivellia metallica</i>	0.010±0.007	0.000±0.000	0.099±0.093	0.031±0.031	0.026±0.010
<i>Steganolauxania</i> sp.	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
<i>Stichopogon</i> sp.	0.005±0.005	0.000±0.000	0.010±0.007	0.000±0.000	0.005±0.005
Homoptera					
<i>Acanalonia latifrons</i>	0.010±0.007	0.083±0.026	0.026±0.010	0.031±0.016	0.057±0.023
<i>Balclutha guajanae</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
<i>Bruchomorpha minima</i>	0.016±0.011	0.000±0.000	0.005±0.005	0.010±0.010	0.016±0.007
<i>Cedusa</i> sp.	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
Cicadellidae undetermined #25	0.010±0.007	0.057±0.051	0.000±0.000	0.000±0.000	0.068±0.037

Table 5.4. Continued.

Species/Morphospecies	Treatment				Reference
	Control	ULW*	Bum	Felling	
Cicadellidae undetermined #27	0.010±0.010	0.005±0.005	0.000±0.000	0.016±0.011	0.125±0.078
Cicadellidae undetermined #28	0.031±0.021	0.016±0.016	0.089±0.082	0.026±0.020	0.063±0.040
Cicadellidae undetermined #31	0.010±0.007	0.000±0.000	0.037±0.031	0.005±0.005	0.000±0.000
Cicadellidae undetermined #32	0.005±0.005	0.000±0.000	0.010±0.010	0.005±0.005	0.010±0.007
Cicadellidae undetermined #33	0.000±0.000	0.000±0.000	0.005±0.005	0.005±0.005	0.005±0.005
Cicadellidae undetermined #35	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.010
Cicadellidae undetermined #37	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Cicadellidae undetermined #41	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.026±0.020
Cicadellidae undetermined #42	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.026±0.017
Cicadellidae undetermined #44	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.007
Delphacidae undetermined #3	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.005±0.005
Delphacidae undetermined #4	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Delphacidae undetermined #6	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.016±0.016
Delphacidae undetermined #7	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
Delphacidae undetermined #8	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.052±0.033
Delphacidae undetermined #9	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.016±0.016
Dictyopharidae undetermined #2	0.010±0.007	0.000±0.000	0.026±0.017	0.021±0.015	0.021±0.013
Dictyopharidae undetermined #3	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.031±0.031
<i>Draeculocephala septemguttata</i>	0.010±0.007	0.000±0.000	0.010±0.007	0.000±0.000	0.026±0.015
<i>Empoasca</i> spp.	0.010±0.010	0.000±0.000	0.005±0.005	0.000±0.000	0.005±0.005
<i>Erythroneura</i> spp.	0.010±0.007	0.005±0.005	0.047±0.030	0.089±0.042	0.245±0.087
<i>Eutettix tristis</i>	0.021±0.021	0.005±0.005	0.010±0.010	0.021±0.021	0.057±0.031
<i>Hysteropterus punctiferum</i>	0.089±0.034	0.062±0.021	0.026±0.012	0.156±0.076	0.047±0.013
<i>Liburnella ornata</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.016±0.011	0.010±0.010
<i>Metcalfa pruinosa</i>	0.146±0.075	0.198±0.122	0.516±0.269	0.031±0.020	0.245±0.110
<i>Oecleus</i> sp.	0.042±0.028	0.021±0.010	0.099±0.049	0.052±0.016	0.000±0.000
<i>Oliarus vicarius</i>	0.016±0.007	0.005±0.005	0.021±0.015	0.021±0.007	0.005±0.005
<i>Paraphlepsius mimus</i> (?)	0.010±0.007	0.005±0.005	0.005±0.005	0.010±0.007	0.088±0.051
<i>Penthimia</i> sp.	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
<i>Polana quadrinotata</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005	0.005±0.005
<i>Rhynchomitra lingula</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.010±0.010
<i>Rugosana querci</i>	0.000±0.000	0.000±0.000	0.016±0.011	0.000±0.000	0.000±0.000
<i>Scaphoideus</i> sp.	0.000±0.000	0.016±0.007	0.026±0.020	0.000±0.000	0.000±0.000
<i>Scaphytopius rubillus</i> (?)	0.057±0.025	0.084±0.036	0.047±0.024	0.016±0.007	0.146±0.100
Hymenoptera					
<i>Apanteles</i> sp.	0.010±0.007	0.036±0.015	0.031±0.021	0.042±0.025	0.052±0.013
<i>Aspilota</i> sp.	0.005±0.005	0.005±0.005	0.000±0.000	0.010±0.010	0.000±0.000
<i>Brachymyrmex depilis</i>	0.052±0.025	0.021±0.010	0.057±0.023	0.057±0.040	0.052±0.019
<i>Brachymyrmex musculus</i>	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.036±0.020
<i>Camponotus socius</i>	0.010±0.010	0.005±0.005	0.005±0.005	0.000±0.000	0.016±0.007
<i>Chelonus</i> sp.	0.016±0.007	0.031±0.021	0.042±0.019	0.083±0.083	0.000±0.000
<i>Crematogaster ashmeadi</i>	0.193±0.074	0.250±0.069	0.448±0.399	0.224±0.077	0.125±0.048
<i>Dolichoderus pustulatus</i>	0.021±0.015	0.016±0.011	0.031±0.031	0.036±0.015	0.036±0.026
<i>Formica pallidefulva</i>	0.000±0.000	0.010±0.010	0.000±0.000	0.000±0.000	0.000±0.000
<i>Forelius pruinosis</i>	0.146±0.040	0.166±0.089	0.062±0.018	0.172±0.066	0.010±0.007
<i>Formica schaufussi</i>	0.000±0.000	0.021±0.015	0.047±0.026	0.026±0.010	0.000±0.000
<i>Heterospilus</i> sp.	0.078±0.013	0.047±0.019	0.031±0.016	0.115±0.019	0.036±0.025
<i>Leptothorax pergandei</i>	0.068±0.032	0.073±0.033	0.016±0.007	0.026±0.015	0.016±0.007
<i>Leptothorax texanus</i>	0.083±0.060	0.031±0.014	0.026±0.015	0.031±0.008	0.031±0.020

Table 5.4. Continued.

Species/Morphospecies	Treatment				Reference
	Control	ULW®	Burn	Felling	
<i>Mirax</i> sp.	0.010±0.007	0.005±0.005	0.005±0.005	0.000±0.000	0.000±0.000
<i>Monomorium viride</i>	0.193±0.065	0.062±0.045	0.073±0.030	0.089±0.059	0.057±0.051
<i>Muesebeckia</i> sp.	0.016±0.011	0.000±0.000	0.000±0.000	0.005±0.005	0.010±0.007
<i>Opius</i> sp.	0.016±0.007	0.047±0.026	0.036±0.010	0.042±0.013	0.010±0.010
<i>Orasema</i> nr. <i>bakeri</i>	0.005±0.005	0.010±0.007	0.010±0.007	0.016±0.016	0.010±0.007
<i>Orthostigma</i> sp.	0.005±0.005	0.016±0.016	0.000±0.000	0.000±0.000	0.000±0.000
<i>Paratrechina wojciki</i>	0.052±0.016	0.042±0.028	0.089±0.044	0.047±0.021	0.016±0.016
<i>Phanerotoma</i> sp.	0.021±0.013	0.010±0.007	0.026±0.017	0.026±0.020	0.010±0.007
<i>Pheidole adrianoi</i>	0.031±0.020	0.037±0.031	0.016±0.007	0.021±0.015	0.021±0.010
<i>Pheidole dentata</i>	0.000±0.000	0.021±0.015	0.005±0.005	0.000±0.000	0.000±0.000
<i>Pheidole floridana</i>	0.057±0.032	0.010±0.007	0.031±0.020	0.042±0.025	0.078±0.018
<i>Prenolepis imparis</i>	0.000±0.000	0.016±0.011	0.000±0.000	0.005±0.005	0.042±0.031
<i>Pseudomyrmex ejectus</i>	0.005±0.005	0.000±0.000	0.000±0.000	0.010±0.010	0.000±0.000
<i>Pseudomyrmex pallidus</i>	0.016±0.007	0.026±0.026	0.005±0.005	0.005±0.005	0.005±0.005
<i>Solenopsis abdita</i>	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000
<i>Solenopsis picta</i>	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005	0.005±0.005
<i>Trachymyrmex septentrionalis</i>	0.026±0.020	0.120±0.107	0.016±0.016	0.005±0.005	0.005±0.005
Araneae					
<i>Acacesia hamata</i>	0.000±0.000	0.016±0.007	0.005±0.005	0.010±0.007	0.000±0.000
<i>Acanthepeira stellata</i>	0.005±0.005	0.005±0.005	0.005±0.005	0.016±0.016	0.005±0.005
<i>Araneus</i> sp.	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
<i>Eris</i> sp.	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Eustala</i> sp.	0.115±0.019	0.141±0.029	0.073±0.045	0.109±0.018	0.031±0.016
<i>Gea heptagon</i>	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
<i>Habronattus</i> sp.	0.005±0.005	0.010±0.010	0.005±0.005	0.010±0.007	0.000±0.000
<i>Hamataliwa</i> sp.	0.000±0.000	0.005±0.005	0.000±0.000	0.000±0.000	0.005±0.005
<i>Hentzia</i> sp.	0.005±0.005	0.000±0.000	0.021±0.010	0.010±0.007	0.005±0.005
<i>Larinia</i> sp.	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.016±0.016
<i>Maevia</i> sp.	0.000±0.000	0.010±0.007	0.000±0.000	0.010±0.010	0.000±0.000
<i>Mangora gibberosa</i>	0.052±0.019	0.068±0.040	0.010±0.010	0.005±0.005	0.010±0.010
<i>Marpissa</i> sp.	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
<i>Mecynogea lemniscata</i>	0.000±0.000	0.010±0.007	0.005±0.005	0.005±0.005	0.005±0.005
<i>Mimetus</i> sp.	0.005±0.005	0.010±0.007	0.026±0.010	0.021±0.010	0.010±0.007
<i>Misumenoides formosipes</i>	0.026±0.020	0.016±0.016	0.026±0.020	0.016±0.007	0.047±0.036
<i>Misumenops</i> sp.	0.026±0.012	0.021±0.015	0.031±0.025	0.021±0.021	0.057±0.036
<i>Ocrepeira</i> sp.	0.005±0.005	0.005±0.005	0.000±0.000	0.000±0.000	0.000±0.000
<i>Oxyopes</i> sp.	0.000±0.000	0.010±0.007	0.000±0.000	0.005±0.005	0.016±0.011
<i>Peucetia viridans</i>	0.016±0.016	0.021±0.010	0.026±0.026	0.026±0.010	0.016±0.007
<i>Phidippus</i> sp.	0.000±0.000	0.000±0.000	0.005±0.005	0.000±0.000	0.016±0.016
<i>Sarinda</i> sp.	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.005±0.005
<i>Tibellus oblongus</i>	0.005±0.005	0.000±0.000	0.005±0.005	0.016±0.016	0.031±0.020
<i>Tmarus</i> sp.	0.146±0.104	0.057±0.020	0.094±0.061	0.021±0.007	0.083±0.039
<i>Xysticus</i> sp.	0.036±0.015	0.031±0.014	0.021±0.015	0.052±0.029	0.052±0.030
<i>Zygoballus</i> sp.	0.016±0.007	0.010±0.010	0.005±0.005	0.000±0.000	0.021±0.010

Table 5.5a. Correlations among vegetation variables and densities (4 m^{-2}) of arthropod orders and families during pre-treatment and post-treatment years in mixed hardwoods and longleaf pine forests at Eglin Air Force Base, Florida. Blank entries indicate non-significant ($P < 0.05$) correlations.

Variable	Pre-Treatment								
	Spiders	Ants	Flies	Beetles	Hemipterans	Homopterans	Moths	Grasshoppers	Thrips
Basal Area									
Bluejack oak					-0.383	-0.420			-0.364
Longleaf pine									
Persimmon		0.382							
Sand live oak			0.413						
Sand post oak									
Turkey oak									
Yaupon									
Cover									
Graminoid†									0.381
Wiregrass and pineywoods dropseed						0.460			
Forbs									
Woody species		0.439						0.504	
Bare ground									
Woody litter									
Longleaf pine (>25 cm DBH)/100 m ²									
Longleaf pine juveniles (<1.4 m high)									
No. of plant species									

† Includes all grasses and sedges, except wiregrass and pineywoods dropseed.

† Includes all grasses and sedges, except wiregrass and pineywoods dropseed.

Table 5.5a. Continued.

Variable	Post-Treatment								
	Spiders	Ants	Flies	Beetles	Hemipterans	Homopterans	Moths	Grasshoppers	Thrips
Basal area									
Bluejack oak									
Longleaf pine							0.374		
Persimmon									
Sand live oak									0.528
Sand post oak								0.611	
Turkey oak									
Yaupon									
Cover									
Graminoid†					0.421	0.567			
Wiregrass and					0.649				
Pineywoods Dropseed	0.390								
Forbs			-0.406						
Woody species					0.435		0.680		
Bare ground						0.431		0.471	
Woody litter			0.542						
Longleaf pine									
(>25 cm DBH)/100 m ²									
Longleaf pine juveniles									
(<1.4 m high)									
1995									
1996									
Longleaf pine seedlings									
from 1996				-0.374					
No. of plant species									
1995					0.658	0.567	0.485		
1996					0.502	0.380	0.417		

† Includes all grasses and sedges, except wiregrass and pineywoods dropseed.

† Includes all grasses and sedges, except wiregrass and pineywoods dropseed.

Table 5.5b. Correlations among vegetation variables and biomasses (mg/4 m²) of arthropod orders and families during pre-treatment and post-treatment years in mixed hardwoods and longleaf pine forests at Eglin Air Force Base, Florida. Blank entries indicate non-significant ($P < 0.05$) correlations.

Variable	Pre-Treatment								
	Spiders	Ants	Flies	Beetles	Hemipterans	Homopterans	Moths	Grasshoppers	Thrips
Basal Area									
Bluejack oak					-0.398	-0.394			-0.364
Longleaf pine									
Persimmon		0.383							
Sand live oak			0.487		0.479				
Sand post oak			0.396						
Turkey oak									
Yaupon									
Cover									
Graminoid†									0.381
Wiregrass and						0.616			
Pineywoods Dropseed									
Forbs						0.565			
Woody species		0.438				0.370			
Bare ground						0.571		0.494	
Woody litter					0.386				
Longleaf pine									
(>25 cm DBH)/100 m ²									
Longleaf pine juveniles									
(<1.4 m high)									
No. of plant species									

† Includes all grasses and sedges, except wiregrass and pineywoods dropseed.

† Includes all grasses and sedges, except wiregrass and pineywoods dropseed.

Table 5.5b. Continued.

Variable	Post-Treatment								
	Spiders	Ants	Flies	Beetles	Hemipterans	Homopterans	Moths	Grasshoppers	Thrips
Bluejack oak									
Longleaf pine									
Persimmon									
Sand live oak								0.375	0.501
Sand post oak								0.631	
Turkey oak									
Yaupon			0.414						
Cover									
Graminoid†	0.400					0.401			
Wiregrass and					0.623				
Pineywoods Dropseed									
Forbs			-0.389						
Woody species									
Bare ground						0.427		0.498	
Woody litter			0.546						
Longleaf pine									
(>25 cm DBH)/100 m ²									
Longleaf pine juveniles									
(<1.4 m high)									
1995									
1996									
Longleaf pine seedlings			-0.374	-0.361					
from 1996									
No. of plant species									
1995					0.532		0.419		
1996					0.408				

† Includes all grasses and sedges, except wiregrass and pineywoods dropseed.

Table 5.6. Summary of significant post-treatment effects of hardwood reduction techniques on arthropod family and morphospecies densities during spring 1996. Adjusted values measured in each treatment are ranked from highest to lowest. Inequality signs are only presented for significant contrasts. The “?” sign indicates an uncertain outcome for an untested contrast. Pre-treatment effects were factored out of these summary results.

Taxon	Density
	Highest ↔ Lowest
Flatid planthoppers	$B > ULW^* = F/G = C^\dagger$
Grasshoppers	$B > F/G = ULW^* ? C$
Phlaeothripid thrips	$B = F/G = ULW^* = C$
Sminthurid springtails	$B > F/G = C = ULW^*$
<i>Sminthurus carolinensis</i>	$B > F/G = C = ULW^*$
Sampled biomass‡	$B > F/G = ULW^* ? C$
<i>Metcalfa pruinosa</i>	$B > C = ULW^* = F/G$
Leaf beetles	$C ? B ? F/G ? ULW^*$
Dance flies	$F/G > B = C = ULW^*$
Braconid wasps	$F/G = B = C = ULW^*$
Empidid #1	$F/G > ULW^* = B = C$
<i>Erythroneura</i> spp.	$F/G > B > ULW^* = C$
Psocids	$ULW^* = F/G > B = C$
Clubionid spiders	$ULW^* > B = F/G = C$

† Treatments: B = burn; C = control; F/G = felling/girdling; ULW* = herbicide.

‡ Sampled biomass was the sum of grasshopper biomass, which represented >90% of total biomass, adult moth biomass (see densities among treatments in Table 5.2), and biomass of most planthoppers and leafhoppers.

6. POST-TREATMENT EFFECTS OF HARDWOOD REDUCTION TECHNIQUES ON BREEDING AND WINTERING BIRD SPECIES IN SANDHILLS AT EGLIN AIR FORCE BASE, FLORIDA

ABSTRACT

We tested the second year post-treatment effects of three hardwood reduction techniques (ULW[®] form of the herbicide hexazinone, growing season burn, and chainsaw felling/girdling) and a no-treatment control on breeding bird species detection rates and described the winter foraging of common bird species in fire-suppressed and degraded longleaf pine (*Pinus palustris*)-dominated sandhills at Eglin Air Force Base, Florida. Of 18 common breeding bird species tested, only red-cockaded woodpeckers (*Picoides borealis*) and pine warblers (*Dendroica pinus*) significantly responded to treatments. Detection rates for the longleaf pine-associated red-cockaded woodpecker were significantly greater in ULW[®] than other treatments and marginally significantly greater in felling/girdling than burn plots. Compared to controls, pine warblers achieved a 4-fold increase in detection rates in felling/girdling plots and a 2-fold increase in ULW[®] and burn plots. Pine warblers responded positively to a reduced midstory. Foraging observations of common wintering birds reflected known habitat associations. Carolina chickadees (*Parus carolinensis*), tufted titmice (*Baeolophus bicolor*), ruby-crowned kinglets (*Regulus calendula*), downy woodpeckers (*Picoides pubescens*), and palm warblers (*Dendroica palmarum*) exhibited higher use of hardwoods relative to pines. The pine-associated red-cockaded woodpecker (*Picoides borealis*), brown-headed nuthatch (*Sitta pusilla*), and pine warbler used longleaf pine nearly exclusively, although pine warblers also foraged on hardwoods. Woodpeckers foraged mainly on tree boles and branches, while the smaller passerines mainly searched from twigs, needles, leaves, and branches, consistent with their respective foraging guilds. Birds used longleaf pine more than all other tree species in both treatment and reference sites. We suggest that pine warblers would be good indicators of ecological change due to their abundance, known habitat and foraging preferences, and rapid responsiveness to habitat modification.

INTRODUCTION

The avian communities of longleaf pine (*Pinus palustris*) forests in the southeastern U.S. can be strongly affected by fire suppression (Engstrom et al. 1984, Engstrom 1993, Wilson et al. 1995). Changes in avian community structure have been shown to reflect vegetation and structural changes as open-canopied pinelands are replaced by closed canopy pine-hardwood forests because of fire suppression. Loss and degradation of pine grasslands throughout the southern U.S. have resulted in the decline of bird species adapted to these habitats (Jackson 1988). The federally endangered red-cockaded woodpecker (*Picoides borealis*), for example, is known to abandon cavities due to hardwood midstory encroachment (Hooper et al. 1980, Conner and Rudolph 1989). Only 11 of 43 breeding bird species were recorded every year during a 15-year study of a northwestern Florida longleaf pine stand following fire exclusion (Engstrom et al. 1984), thus indicating rapid species turnover. Bird species that depend on longleaf pine systems such as Bachman's sparrow (*Aimophila aestivalis*), brown-headed nuthatch (*Sitta pusilla*), and red-cockaded woodpecker declined dramatically or disappeared (Engstrom et al. 1984). Fire suppression was also implicated in the absence of the above species from a mature longleaf pine forest in central Florida (Hirth et al. 1991), and is a major factor in the regional decline of an important game species, the northern bobwhite quail (*Colinus virginianus*) (Brennan 1991).

Efforts to restore community structure and composition, such as prescribed fire and thinning of midstory and co-dominant trees, may benefit the red-cockaded woodpecker and other species of regional concern (Wilson et al. 1995). Wilson et al. (1995) described

increases in 8 of 10 pine-grassland bird species as a result of shortleaf pine (*Pinus echinata*)-bluestem (*Andropogon* sp.) restoration in Arkansas. Provencher et al. (1997) documented initial changes in the index of some breeding birds one year after different hardwood reduction techniques were applied to fire-suppressed longleaf pine-dominated sandhills on Eglin Air Force Base (EAFB), FL. These results, although preliminary, supported the potential for habitat restoration to change the avian community of EAFB. Application of prescribed growing season fire, herbicide, and mechanical hardwood removal to degraded sandhills changed habitat structure and biota, with concomitant changes to the avian community. For example, species such as northern bobwhite and summer tanager (*Piranga rubra*) that may respond to a more open-canopied forest and/or recently burned habitat have increased. Furthermore, the efficacy of the treatment methods to influence the bird community appeared to differ, at least initially (see Provencher et al. 1997).

The present study sought to establish the ecology of longleaf pine forest-associated bird species in the context of a continuing study of the effects and efficacy of different hardwood reduction techniques on the avian community of EAFB. First, we presented pre-treatment data from fire-suppressed and frequently burned sandhills to contrast their respective breeding bird communities. Second, we tested the effects of three hardwood reduction techniques on common breeding birds for the second year post-treatment. Findings will be contrasted with first year post-treatment results. Third, we examined the general foraging patterns of common wintering birds as a natural history description to establish further study of their response to hardwood reduction treatments.

SITE DESCRIPTION

EAFB occupies the southern portions of Walton, Okaloosa, and Santa Rosa Counties in the western Florida Panhandle (Fig. 3.1 in Chap. 3). EAFB is bordered by the Yellow River and Alaqua Creek to the north and east and by the Gulf of Mexico and Choctawhatchee Bay to the south and east. Sandhill sites selected for this study varied in degree of past fire frequency, soil alteration, and groundcover dominants.

The climate is temperate with mild winters and hot, humid summers. Winters tend to be somewhat milder near the coast compared to the inland regions (Chen and Gerber 1990). The mean annual temperature is 18.3 °C, with approximately 275 freeze-free days per year. Thunderstorms and lightning strikes are frequent during the summer months. Mean annual precipitation is 158 cm per year (DoD-Air Force 1995). Monthly precipitation levels peak slightly during late spring and early summer months and decrease during the winter months. Snow accumulation is rare. Tropical storms are frequent along the Gulf Coast of Florida and neighboring states. Between 1871 and 1985, 115 tropical storms and hurricanes made landfall within 110 km of EAFB (NOAA 1994).

The terrain is level to gently rolling with occasional areas of steeply inclined terrain. Elevation ranges from 0-100 m above sea levels and the landscape generally slopes to the southwest toward the Gulf of Mexico. The Citronelle Formation (Pleistocene) is the dominant parent material for the surficial sediments (Overing et al. 1995). It mostly consists of deep sand (>90%).

With a historically high fire frequency (approximately 1-10 years), the longleaf pine sandhill community is characterized by a nearly pure overstory of longleaf pine, a sparse midstory of hardwoods (*Quercus* spp. [oaks] and others), and a diverse groundcover dominated by native perennial graminoids and forbs (Myers 1990). Following extended periods of fire suppression, a dense midstory of oaks and other hardwood tree species develops, and groundcover of graminoids and forbs significantly decreases (White et al. 1991, Robbins and Myers 1992). Fire suppression also results in increased importance of medium-statured shrubs (e.g., blueberries [*Vaccinium* spp.]) and woody vines (e.g., catbrier [*Smilax*

spp.]) in the understory. Forestry and military activities have resulted in significant soil alteration across EAFB. Earth mining, roads, clearcuts, selective timber harvest, stumping, fire breaks, tank activity, and other activities now create a mosaic of disturbances in both fire-suppressed and frequently-burned longleaf pine stands at EAFB.

METHODS

Experimental Design

Restoration blocks. Six blocks of four, 81-ha (200-acre) fire-suppressed restoration plots were established along a west/east transect of EAFB (Fig. 3.1 in Chap. 3: B-7; Wolf Creek; Metts Creek; Malone Creek; Exline Creek; C-72). Within each of the six blocks created, site characteristics were considered sufficiently homogeneous among the member plots for our study to conform to a randomized complete block design (Steel and Torrie 1980). In keeping with this design, each plot within a block was randomly assigned without replacement to either control designation (no treatment), or to one of the three following restoration treatments: growing season burn (May and June); herbicide (ULW[®], the granular form of hexazinone with 75% active ingredient applied at a rate of 2.44 kg/ha [2 lb./acre]); and oaks and sand pine felling/girdling by chainsaw (slash not removed) (Fig. 3.2 in Chap. 3).

All plots were selected if they were located in areas larger than 81 ha (200 acres) that contained a high density of relatively large diameter hardwood trees, had been fire-suppressed for several decades, and were adjacent to three other such sites. Plots had a relatively sparse herbaceous understory and a thick litter of hardwood leaves interspersed with bare ground. The occurrence of recent small wildfires (<0.5 ha [1 acre]) or small creeks within a plot did not disqualify it from consideration.

Reference blocks. A total of six 81-ha (200-acre) frequently-burned longleaf sandhill reference plots were also established (Fig. 3.1 in Chap. 3: A-77; A-78; and B-75) to provide objective goals for the restoration of fire-suppressed plots. Reference plots were not part of the restoration experimental design described above, but are a critical research component because they provide a benchmark for measurement of the success and efficacy of the restoration treatments applied. Reference plots were chosen on the basis of the following criteria: a square area larger than 81 ha (200 acres); uneven age distribution of longleaf pine; presence of old-growth longleaf pine; abundance of fine fuels interspersed with bare ground; openness of the forest; presence of active red-cockaded woodpecker clusters; and a history of frequent growing season fires. Because of the difficulty in satisfying these requirements, we located only three blocks, each consisting of two 81-ha (200-acre) plots.

The three restoration techniques were applied to fire-suppressed plots during the spring and early summer of 1995 following one year of pre-treatment data collection. ULW[®] herbicide and felling/girdling plots received their respective treatments during this time but were not burned until 3 March to 14 April 1997 because of concerns about catastrophic fires from heavy fuel load production. As a result, during the May-June 1997 (immediately post-burn) breeding bird survey, some of these plots exhibited considerable charring.

Avian Sampling

Original proposals for investigating the effects of restoration treatments on EAFB's birds involved point count sampling in both the breeding and non-breeding seasons. However, the winter bird community was found to violate some of the key assumptions of the point count method; namely that male songbirds are primarily territorial and sing frequently, and are more or less evenly distributed (see Ralph et al. 1995). In winter, many landbird species associate in mixed-species flocks that can range over a wide area (Gaddis 1983, Yahner 1985), so that chances of intercepting a feeding flock during a point count are reduced (Yahner 1985). The

majority of EAFB's winter birds were observed to conform to this community structure during the winter.

In addition, because there was a possibility that wide-ranging birds in flocks could utilize several treatments within a block during the same day, a basic assumption of parametric statistics—that bird detections are independent of treatments—would be violated during the winter sampling (Sokal and Rohlf 1981). While our previous winter season point count data were considered adequate to examine the general wintering bird community of pre-restoration sandhills, analysis of winter point count data (unpublished) indicated that variations in detectability were too great for the majority of species to show differential preference for treatment types, unlike during the breeding season. In response to these problems, we decided to study winter bird foraging and flock composition and abundance patterns in the winter of 1996/97 and thereafter instead of conducting winter point counts. Focal-bird (Block and Brennan 1993) approaches, such as foraging studies, can provide a more in-depth look at specific avian habitat relationships than abundance data and may prove to be a better measure of the treatment effects on wintering birds.

Breeding and Wintering Season Point Counts. In order to estimate the abundance of breeding (May-June) and wintering (December-March) bird species during the pre- and post-treatment periods of the study, the 24 restoration plots were surveyed using a variation of the unlimited distance point count method (after Blondel et al. 1991). The six reference plots were similarly indexed to provide a potential target for the fire-suppressed restoration bird community. On restoration plots, point counts were conducted from four permanent stations erected uniformly (approximately 200 m apart) within the 20-ha (50-acre) sampling corner of each plot (Fig. 6.1). Because detectability decreases with distance, this station arrangement alleviates potential for recording individuals that may actually be within adjacent plots of a given block. On reference plots, point counts were conducted from eight stations uniformly located approximately 200 m apart in plot centers (Fig. 6.1). The difference in station arrangement between restoration and reference plots reflects restrictions imposed by other aspects of the study design (see Chapter 3).

One year of pre-treatment surveys were conducted on restoration plots during the 1994 breeding season and the 1994/95 wintering season. Two post-treatment surveys were conducted during the 1994-95 breeding seasons and one during the 1995/1996 wintering season. Restoration plots were not sampled during the 1995 breeding season because of ongoing herbicide and felling/girdling operations during this period. Reference plots were sampled during breeding seasons 1994-97 and wintering seasons 1994/95 and 1995/96. Surveys were timed to coincide with peak territoriality and/or stability of the breeding and wintering avian communities.

Data Collection Timeline.

Variable	Beginning date	Ending date
Breeding Season (I) ^a	4 May 1994	30 June 1994
Wintering Season (I)	1 December 1994	13 March 1995
Breeding Season (reference plots only)	5 May 1995	30 June 1995
Wintering Season (II)	1 December 1995	13 March 1996
Breeding Season (II)	15 May 1996	30 June 1996
Winter Foraging (II)	31 December 1996	3 March 1997
Breeding Season (III)	7 May 1997	20 June 1997
Winter Foraging (III)	9 December 1997	Ongoing February 1998

^a Numerals in parentheses indicate study phase: I = pretreatment, II = first year post-treatment; III = second year post-treatment.

Each sampling day, one experimental block (i.e., four restoration or two reference plots) was surveyed for birds during the morning. Counts commenced when daylight reached a minimum level necessary to visually identify birds. For each 8-minute point count, the species, number, and location of all birds seen or heard using the plot were recorded. Birds flying over plots were only recorded if there was evidence that they were foraging over the plot (e.g., American kestrel [*Falco sparverius*]) or had been perched in the plot prior to taking flight. An entire block (16 total stations) was surveyed by two observers in approximately 3 hours. Thus, at a rate of 1 block/day, one full round of counts in which all nine restoration and reference blocks were surveyed was completed in nine days. This rate allowed a maximum of 3-4 rounds to be conducted within the specified time frame, dependent on weather and military mission activity.

The order of survey for each block within a given round of bird surveys was determined randomly, and then on the basis of gaining clearance to closed/restricted areas. For spring 1994 and 1996 and winter 1994/95 and 1995/96, survey order of individual restoration plots on a given day was determined randomly. A further restriction was that, by round #4, each of the four plots comprising the block would be sampled 1st, 2nd, 3rd, and 4th in order only once. For reference blocks, survey order of individual plots on a given day was similarly randomized, except that each of the two plots comprising these blocks was to be sampled first and second in order exactly twice by round #4. These measures attempted to minimize temporal bias in survey data by accounting for the tendency of bird activity, and therefore detectability potential, to decline throughout the morning and to vary from day to day. This sampling arrangement was changed during spring 1997 to produce a more systematic, but random order of restoration plot survey by treatment type for reasons discussed below.

Winter Bird Foraging Study. The method presented here was considered a pilot study because of sampling effort constraints imposed by having only one observer during the winter 1996/97 and because of the need to develop the method specifically for EAFB. We were aware of only one study of this nature in longleaf pine-dominated habitat. Morse (1970) studied mixed-species flocks in a longleaf pine stand in Louisiana, but his method was deemed inappropriate for this study due to our experimental design and large between-study differences in habitat and bird community structure. In addition, the majority of foraging studies of mixed-species flocks have been done in the tropics with canopy insectivores or in temperate areas with parid flocks (see Morrison et al. 1990, review by Powell 1985). These studies were also determined not to be applicable to EAFB's winter bird community of residents and short-distance migrants.

Preliminary investigation of avian foraging flocks during winter 1996/97 consisted of randomized visits to restoration and reference plots, during which the observer attempted to locate a flock over a 2-hr period. Each plot was visited twice over the sampling period and a maximum of 2 plots were completed per day. In addition to treatment, time of day and date were randomized to avoid potential temporal and seasonal bias. Once a flock was encountered, species composition and abundance were recorded and behavioral observations were taken. To minimize bias, the observer attempted to randomly select birds for observation in order to not over-represent a particular bird species or habitat location during the flock observation period. Due to the difficulty in obtaining ground foraging observations, we recorded birds flushed from the ground by observer disturbance or birds that flew to or from the ground. Length of the flock observation period, weather, time of day, and presence of potential flock predators were also recorded.

Each individual bird observation consisted of the observer sighting the bird with binoculars and following it until a subjective determination of its behavior was made. Non-foraging behaviors were recorded, but not used in the subsequent analyses. Habitat and foraging variables measured for each bird sighted were: 1) its position in the habitat (ground, slash, or shrub; tree-bole divided into low, mid, or upper; and tree-canopy divided into low, mid, or upper); 2) tree species and viability (live, dead, or diseased); 3) estimated tree DBH (5 cm

classes); 4) substrate on which the bird foraged; 5) foraging maneuver used; and 6) estimated height of foraging in meters (see Appendix E for description of substrates and foraging maneuvers). Bird position, foraging maneuver, substrate, and height were dictated into a micro-cassette recorder; all other data were recorded on data sheets. Recorded foraging observations were later transcribed onto the data sheets to coincide with their respective habitat variables.

Statistical Analyses

Community Profiles. We used pre-treatment point count data to examine the breeding bird communities in restoration and reference habitats. The respective data sets from combined restoration (N=384) and reference (N=188) breeding season point counts were analyzed using basic statistics. We then graphed the means and variances of the 10 most common species within restoration and reference habitats to compare their respective communities. It is important to note that specific restoration and reference species values are not directly comparable because of different sample sizes and point count station arrangement (see above), and because reference plots are separate from the restoration experiment. However, due to the relatively large sample sizes resulting from the combined data sets, we believe this analysis of detection rates at least typifies the bird communities of restoration and reference plots.

Breeding Bird Data. We graphed only the pre- and second-year post-treatment medians of plot averages, 25 and 75% quartiles, and minimum and maximum values of only those species that showed significant differences by treatment and the federally endangered red-cockaded woodpecker. (Fifty percent of values are smaller or greater than the median. The 25 and 75% quartiles contain the 50% central values of the data; therefore, three of six replicates closest to the median are contained within the 25 and 50% quartiles.) We chose to graph the median and 25 and 75% quartiles because they show the data's actual distribution, but the statistical tests described below and reported on the figures are based on means and variances. When a variable was not significantly affected by restoration treatments, we tabulated its mean and standard error per treatment and reference plots.

Restoration treatment effects on breeding bird detection rates were tested with a randomized complete block analysis of covariance (ANCOVA) (Steel and Torrie 1980) for selected species in restoration plots. We tested the effect of pre-treatment data (i.e., covariate) on post-treatment data as part of the tests for restoration treatments in an ANCOVA for restoration plots. In ANCOVA, pre-treatment data were used to adjust post-treatment averages to account for differences among treatments that existed prior to treatment application. The adjusted averages were the values used in the figures. Adjusting means involved using the estimated regression slope obtained from ANCOVA to calculate the expected dependent variable when all independent variables were set to a common average and regression slope (Steel and Torrie 1980). When pre-treatment data are available and meet the assumptions of ANCOVA, this latter method is more precise and powerful than analysis of variance (ANOVA) (Steel and Torrie 1980, Sokal and Rohlf 1981, Streng et al. 1993).

We performed three independent contrasts to compare treatment means. Because it is only possible to perform a maximum number of contrasts that is equal to the degrees of freedom for restoration treatments (3 df) (Sokal and Rohlf 1981), which is less than the number of possible comparisons, we strategically chose to compare the following treatments: control versus burn, burn versus ULW®, and burn versus felling/girdling. In the first contrast we tested whether doing nothing or maintaining fire suppression (control) performed as well as burning. Burning is the management default at EAFB because it is the least expensive management tool available to managers and because chronic fires would characterize the maintenance condition of sandhills. Both felling/girdling and ULW® are more expensive management techniques in comparison to burning, and their efficacy should be compared to burning, but not to fire suppression.

We performed ANCOVAs on detection rates using a computer randomization test (Edgington 1987). Two reasons justified the extra effort of programming the tests. First, we had too many bird species (>50) to consider and it became cumbersome and very time-consuming to separately test each variable with commercial software. Thus, we wrote a computer program that processed all variables at the same time. Second, many common species exhibited low and patchy detection rates such that their frequency distributions approach binary distributions with high variances, which parametric statistics cannot handle. The randomization procedure is distribution free, but still depends on homogeneous variances among treatments. Briefly, the purpose of the computer test was to create a random distribution for a chosen statistic (e.g., variance) representing the original data through random permutations among treatments (i.e., the null hypothesis was that the observations can belong to any treatment), and then to determine if the observed statistic from the original unpermuted data was greater than or equal to the 95% of the random values (i.e., if it is in the 5% tail of the distribution). If the original statistic was in the 5% tail of the distribution, the null hypothesis of no difference among restoration treatments was rejected with a significance probability that was equal to $1 - (\text{relative rank of the original statistic in the distribution})$ (Edgington 1987). The three independent contrasts were performed with the same set of permutations and methods, but we used the "t" statistic with standard errors for two adjusted means calculated from ANCOVA (Steel and Torrie 1980) to compare means. We permuted the original data 10,000 times to create a random distribution for each variable. The effect of pre-treatment data on post-treatment values (covariate effect) was determined directly from the F-ratio calculated with the original data, and thus, not the result of permutations. (A new randomization procedure would be required to test the covariate effect.) The significance probability for the covariate effect was approximately determined from a table. We partitioned sum of squares following the ANCOVA formulas in Steel and Torrie (1980) and Cochran and Cox (1957).

Most of the reported variables needed transformation, because they displayed non-normal distributions and heterogeneous variances, which are violations of parametric and, in the case of heterogeneous variances, distribution-free statistics. $\text{Ln}[\sqrt{(X+1/2)}]$ was used on all point counts for this analysis (Sokal and Rohlf 1981) because the square-root or log transformation alone could not homogenize variances whereas they could when used in combination.

For simplicity and ease of reading, we have termed the tests of restoration treatment in the statistical tables as "restoration". It should also be noted that we did not test the significance of the block effect, which refers to the source of variation caused by the spatial difference among blocks, because it is impossible to mathematically test such an effect in block designs for which the treatment is an applied, repeated, and controlled (i.e., fixed) manipulation (Cochran and Cox 1957; Steel and Torrie 1980). The block*restoration treatment interaction was the error term (i.e., denominator in the F statistic) needed to test the effect of the restoration treatment.

Wintering Foraging Study Analyses. We created tables summarizing foraging maneuver, substrate, and tree use per bird species and tree species attributes. A minimum of 30 foraging observations per bird species by treatment type was considered necessary for statistical tests (Brennan and Morrison 1990). Since few species met this requirement, we simply graphed species habitat use by proportion of tree species, substrate, and foraging maneuver if sample sizes were adequate. We also graphically presented the proportion of tree species use for each restoration treatment and the reference type by all species observed to examine differences in tree foraging availability among plot types. We did not test the significance of treatment effects on these data because of their preliminary nature and sampling constraints (see above).

Foraging Attributes Used To Graph Substrate and Maneuver Use.

Foraging Substrates		Foraging Maneuvers
<i>Woody</i>	<i>Foliage</i>	Flake
Bole	Cone	Glean
Branch	Leaf	Peck
Stub	Needle bundle	Probe
Twig	Needle	Search
		Other (see Appendix E)

RESULTS

Avian Assemblage Analysis. American crow (*Corvus brachyrhynchos*) was the most frequently detected bird species in restoration and reference habitats. However, it was not included in this analysis because of its extreme detectability by sound relative to the other species and ubiquitous occurrence across the landscape. The restoration and reference bird assemblages were determined by the 10 next most frequently detected species. They differed in composition and relative ranking between habitats (Fig. 6.2). Five of the 10 reference species are considered pine-grassland associates (Bachman's sparrow, northern bobwhite, pine warbler (*Pinus dendroica*), red-cockaded woodpecker, red-headed woodpecker [*Melanerpes erythrocephalus*] [Wilson et al. 1995]). American kestrels require an open understory to hunt prey (Hoffman and Collopy 1988). The remaining species are more generalized in their habitat associations or prefer other breeding habitats in the southeastern U.S. (Hamel 1992).

Of the 10 species in restoration habitats, only 2 (pine warbler and northern bobwhite) are pine-grassland associates and are ranked lower in order of relative importance. The remaining eight species in the southeastern U.S. either exhibit preferential use of mixed pine-hardwood habitats (great crested flycatcher [*Myiarchus crinitus*], northern cardinal [*Cardinalis cardinalis*], summer tanager, tufted titmouse [*Baeolophus bicolor*]), show distinct preference for hardwood habitats (pileated woodpecker [*Dryocopus pileatus*]), or are habitat generalists relative to this study area (blue jay [*Cyanocitta cristata*], common nighthawk [*Chordeiles minor*], red-bellied woodpecker [*Melanerpes carolinus*]) (Hamel 1992).

Breeding Birds. Nineteen out of 51 breeding bird species detected in spring 1997 (see Appendix D for the full species list) were retained in this study (Table 6.1). These 19 species were chosen because they were the most frequently detected or were species of concern. The latter include Bachman's sparrow, red-cockaded woodpecker, northern bobwhite quail, and the neotropical migratory species blue grosbeak (*Guiraca caerulea*) and summer tanager. Only 18 species (not including Bachman's sparrow) had sufficiently high detection rates in all treatments to allow for tests of treatment effects (Table 6.2). Bachman's sparrow was not included in the statistical analysis, mainly because of its low detection rates.

Pine warbler and red-cockaded woodpecker were the only species that significantly responded to restoration treatments in 1997 (Table 6.2). Adjusted median pine warbler detection rates showed the strongest response to restoration treatments ($P < 0.0032$; Table 6.2). Detection rates were higher in burn plots compared to control plots ($P < 0.0236$; Table 6.2; Fig. 6.3). Adjusted median detection rate observed in felling/girdling plots was approximately twice that of burn plots ($P < 0.0272$; Table 6.2), which were not significantly different from those observed in ULW[®] plots ($P < 0.1919$; Table 6.2).

Adjusted median red-cockaded woodpecker detection rates were significantly higher in ULW[®] plots compared to burn plots ($P < 0.0017$; Table 6.2, Fig. 6.3). Adjusted median detection rates in burn plots were not significantly different than in control plots ($P < 0.3616$; Table 6.3) and were marginally significantly different from felling/girdling plots ($P < 0.0661$;

Table 6.3). (The felling/girdling versus control contrast was not tested, but may be significant.)

Bachman's sparrows were found only in ULW®, felling/girdling, and reference plots during the pre-treatment phase of the study (Table 6.1). Two-years post-treatment, these birds were detected only in burn, felling/girdling, and reference plots. Detection rates were always low.

In 1997, average detection rates of northern bobwhite quail were higher in all treated plots compared to the control, but these differences were not significant ($P < 0.7642$; Tables 6.1 and 6.2). Although high variability resulted in no statistical treatment differences, burn plots tended to support the greatest detection rates, which were approximately twice those of the control.

Blue grosbeaks and summer tanagers had common responses to burning; they reached their highest detection rates in burn plots (Table 6.1). Their detection rates differed mostly from control plots; blue grosbeaks were absent from controls, whereas summer tanagers reached their second highest detection rates there. These were not significant, however.

Winter Bird Foraging. Ten of the 33 species observed foraging during winter 1996/97 (see Appendix D) had adequate sample sizes to examine the relative proportional use of the various foraging and habitat attributes (Figs. 6.4-6.6). Use of tree species by these birds are shown in Fig. 6.4. Species that exhibited higher use of hardwoods relative to pines were Carolina chickadees (*Parus carolinensis*), tufted titmice, ruby-crowned kinglets (*Regulus calendula*), downy woodpeckers (*Picoides pubescens*), and palm warblers (*Dendroica palmarum*). Among these species, differences existed in their relative use of different hardwood species. Use of turkey oak (*Quercus laevis*) was high for Carolina chickadees, tufted titmice, and downy woodpeckers; less so for palm warblers. Red-cockaded woodpeckers were only observed to use turkey oak <1% of the observation total. Ruby-crowned kinglets exhibited high use of sand live oak (*Quercus geminata*) and yaupon (*Ilex vomitoria*). Seven of the 10 bird species used sand live oak to various degrees, whereas red-cockaded woodpeckers and brown-headed nuthatches were never observed to use this species, and American goldfinches (*Carduelis tristis*) used it very infrequently.

Longleaf pine was used by all 10 species, among which red-cockaded woodpecker, brown-headed nuthatch, and American goldfinch used it nearly exclusively. Longleaf pine was the dominant tree used by pine warblers. Among the picids, red-cockaded woodpeckers and red-bellied woodpeckers showed considerable overlap of longleaf pine use, although red-bellied woodpeckers also used hardwoods (approx. 20% of observation total). Downy woodpeckers showed a more even affinity for both hardwoods and softwoods although hardwood use predominated. Relatively high use of sand pine was largely restricted to palm warblers. Palm warblers, Carolina chickadees, and tufted titmice appeared to use hardwoods and softwoods somewhat more evenly than the other species. Several species exhibited minor use of weeping haw (*Crataegus lacrimata*), sand post oak (*Quercus margaretta*), and bluejack oak (*Quercus incana*).

Foraging substrate use is shown in Fig. 6.5. High use of woody substrates was evident for most species except the American goldfinch. Use of tree boles (predominantly bark foraging) was evident especially for red-cockaded woodpeckers and red-bellied woodpeckers, whereas downy woodpeckers showed a greater affinity for branches. As with tree species use (Fig. 6.4), red-cockaded and red-bellied woodpeckers overlapped considerably in substrate use (Fig. 6.5). Carolina chickadees and tufted titmice showed rather different woody substrate use. Relative percent use of twig versus branch substrates differed for these two species; in addition, stub use by tufted titmice was more than twice that of Carolina chickadees.

Pine and palm warblers appeared to use both woody and foliage substrates more evenly. American goldfinches were observed to forage on longleaf pine cones intensively. With the

exception of palm warblers and ruby-crowned kinglets, all species were observed using longleaf pine seeds. Pine and palm warblers used needle and needle bundle to a high degree, although they differ in pine species use (Fig. 6.4). Hardwood leaf use was high for ruby-crowned kinglets relative to needle bundle use. Differentiation between foraging on fine twigs and leaves for this species is difficult because of its observed high rate of foraging on both. The other species are more easily separated into foraging substrate categories although Carolina chickadees and tufted titmice also exhibited this problem to a lesser degree.

Fig. 6.6 shows the types and relative percent of common foraging maneuvers observed. Observations of the general search foraging strategy predominated. Of the 10 species, woodpeckers exhibited more specific foraging techniques than the other birds, except for American goldfinch. Woodpeckers showed more pecking and probing than the other species. Red-bellied woodpecker appeared to probe more than red-cockaded woodpecker, mostly on the cones of longleaf pine and also in hardwood cavities (data not presented). American goldfinch also exhibited more probing relative to the other small birds, as it probed cones for seeds. Longleaf pine needle-bundles were observed to often capture fallen seeds from cones, and pine warblers and American goldfinches were observed to forage from needle bundles for the seeds.

We summarized tree species use per restoration treatment and reference plots across all bird foraging observations combined (including species not presented previously) in Fig. 6.7. cursory analysis of these data indicate longleaf pine was the dominant tree used in both restoration and reference plots, although its frequency was relatively higher in the reference plots. The other hardwood species were foraged on to some extent in all restoration and reference plots with the exception of yaupon in the burn treatment and the reference plots, and sand pine and weeping haw in the reference plots. Combined hardwood use appeared to be greater in all restoration plots relative to reference plots. In addition, burn and control plots showed higher combined hardwood use, although the significance of this has not been tested. Increased sampling effort during the winter of 1997/98 should allow for statistical comparisons of use versus availability that currently are not possible.

DISCUSSION

Avian Assemblage Comparisons. Engstrom (1993) identified red-cockaded woodpecker, brown-headed nuthatch, and Bachman's sparrow to be generally associated with open longleaf pine habitat. In addition to the above species, pine warblers, northern bobwhite quail, and red-headed woodpeckers are considered open pine-grassland associates (Wilson et al. 1995). American kestrels favor open habitats in which to hunt prey and nest (Hoffman and Collopy 1988, Hamel 1992). Consistent with these descriptions, we found that all of the above species (except brown-headed nuthatch), were ranked among the 10 more frequently detected species in the open longleaf pine-grassland reference plots. Only 2 of these species (pine warbler and northern bobwhite quail) were among the 10 more frequently detected in the mixed pine-hardwood restoration plots before treatment application. The disparity between reference and pre-restoration sites may be explained by differences in habitat suitability. According to Engstrom (1993), 36% of species closely associated with frequently-burned longleaf pine habitat forage in the species-rich understory. This is the foraging strategy of northern bobwhite quail (Grelen and Duvall 1966, Ehrlich et al. 1988, Terres 1991) and Bachman's sparrow (Ehrlich et al. 1988). American kestrels, which primarily hunt insects during the breeding season (Ehrlich et al. 1988) and prefer grasshoppers (Terres 1991), also use this stratum for foraging. The red-cockaded woodpecker's intolerance of hardwood midstory encroachment, and the pine warbler's and red-headed woodpecker's preference for open-canopied pine forests explain their high ranking within the reference habitat.

In contrast, the pre-treatment restoration bird assemblage was dominated by species that prefer forests with a significant hardwood component or are able to utilize a wide range of forest types (i.e., habitat generalists). With time, we expect bird assemblages from pre-

restoration habitats to become more similar to those from reference habitats. Most of these pre-restoration bird species, except for habitat generalists, should respond to treatment-induced changes in gross habitat attributes (e.g., reduction of the hardwood midstory; development of a species-rich understory). At least in the case of birds, any forest stand that exhibits the characteristics of the open-canopied longleaf pine ecosystem, such as our reference habitat, should represent a suitable target for restoration. The time required for the convergence of a pre-restoration bird assemblage to a reference bird assemblage should depend on how long it takes for restoration treatments to create a structurally stable environment and prey base.

Four declining bird species were associated with pre-treatment restoration or reference plots, including Bachman's sparrow, northern bobwhite quail, red-cockaded woodpecker, and southeastern American kestrel (*Falco sparverius paulus*). All 4 species were among the top 10 most abundant in EAFB's reference plots, but only northern bobwhite quail was among the top 10 in pre-treatment restoration plots (Fig. 6.2). The two neotropical migratory species summer tanager and blue grosbeak were detected in all plots, but only summer tanagers were frequent enough to rank in the top ten species from pre-treatment restoration plots. Although American kestrels were seen frequently in reference plots, they were infrequently detected in pre-treatment restoration plots despite the availability of grasshoppers (see Fig. 5.11 in Chapter 5).

Treatment Effects on Breeding Birds. During the 1996 breeding season, only great crested flycatcher, mourning dove, northern bobwhite quail, and summer tanager showed significant treatment effects. No significant treatment effects were detected for these species during the 1997 breeding season. Only red-cockaded woodpeckers (Fig. 6.3) and pine warblers (Fig. 6.3) responded significantly to treatments in 1997.

We believe that the significant effect in 1996 may have been partly caused by an unforeseen sampling artifact (this effect may apply to other bird species). Although treatment visitation order per day was randomly determined in 1996, the realized order favored the sampling of control plots later in the morning compared to hardwood reduction plots. Therefore, sampling the burn, ULW®, and felling/girdling plots earlier in the morning would have artificially increased the detection rates of northern bobwhite quail relative to sampling later in controls (Fig. 6.8). Fig. 6.8 shows that northern bobwhite quail sang less frequently (i.e., was detected less) 100 min. after sunrise relative to the other species and reached their highest singing rates immediately after sunrise. In contrast, tufted titmice and pine warblers did not show decreased singing rates with time after sunrise during morning sampling. The detection curves for great crested flycatchers and summer tanagers show a more ambiguous leveling off of detection rates. Data from the 1996 survey, thus, must be treated with caution. We recalculated quail detection rates using observations taken before 0800 hour and still obtained somewhat higher rates in hardwood reduction plots, but the treatment effect was non-significant.

The positive, although non-significant, response to midstory reduction observed in 1997 is consistent with the literature on quail, however (reviewed in Terres 1991, Wilson et al. 1995, Brennan, *in press*). This species prefers open, grassy habitats of mature pine and avoids deep forests (Repenning and Labinsky 1985, Ehrlich et al. 1988, Terres 1991). The lack of significant treatment effects in 1997 as opposed to the suspect 1996 results may be due to the fuel reduction burns of ULW® and felling/girdling plots in the late winter and early spring of 1997 immediately before the breeding bird survey. At the initiation of the breeding bird sampling period in May, many of these plots were charred and supported little groundcover vegetation. Because northern bobwhite quail require sufficient unburned groundcover vegetation for nesting and protection from predators (Brennan 1991), we were not surprised to see fewer quail in these treatments. We expect to see a large increase of northern bobwhite quail in those plots in 1998 and 1999, as found by Wilson et al. (1995). Quail detection rates, however, should have been significantly higher in burn plots in 1997 (not burned in 1997) than in controls if the treatment effect of 1996 had persisted. Burning may have only an initial short-term positive effect on quail numbers through increased food supply (Provencher et al.

1997), unless fire of the proper frequency, intensity, and timing (see Brennan 1991) is maintained long enough for a higher quality habitat to develop.

Pine warblers nest exclusively in pines and associate with habitats rich in older pines (Repenning and Labinsky 1985, Ehrlich et al. 1988, Terres 1991). Pine forests with high hardwood density do not seem to be preferred, although they may be used for nesting and foraging (Fig. 6.2). In the Ouachita National Forest in Arkansas, pine warblers reached their highest densities in thinned and burned treatments, where the midstory was greatly reduced, compared to thinning only and controls (Wilson et al. 1995). Our breeding season results clearly support these findings (Fig. 6.3). In particular, the absence of standing dead and live oaks appeared important to pine warblers since there were twice as many of them detected where oaks were felled than where dead oaks remained standing in the ULW® plots.

Red-cockaded woodpecker detection rates were virtually constant from 1994 to 1996, except in controls where they were undetected in 1996 (Provencher et al. 1997), but increased slightly in all treatment plots in 1997 (Table 6.1). Detection rates decreased in reference plots from 1994 to 1997 (Table 6.1). These results were expected, because expansion of this species into our restoration plots would likely be slowed by the length of time required for cavity excavation and limited availability of old-growth longleaf pine for roosting and nesting (Lennartz et al. 1987, Walters et al. 1992). The cooperative breeding strategy of this species also plays a role in rate of expansion because red-cockaded woodpeckers tend to compete for existing breeding vacancies in occupied territories rather than excavate new cavities in unoccupied ones (Walters et al. 1992).

These inhibitions by red-cockaded woodpeckers to rapid colonization of areas that become suitable through habitat restoration suggest that detectable differences between restoration treatments may be more apparent from the 3rd and 4th post-restoration surveys. In Texas, red-cockaded woodpeckers will use longleaf pine shelterwood stands if they are not regenerated and removed within 10 years (Connor et al. 1991). The observed slight increase in detection rates observed this year may be due to an increase in suitable foraging habitat on our restoration plots. We are aware, however, of the post-restoration (but pre-burn) shift by a cluster formerly occupying an area outside the plot boundaries into one of our ULW® plots (J. Tomcho, Virginia Tech. RCW Research Team; *pers. comm.*). This may have occurred because of a dramatic reduction in midstory-oak foliage by herbicide application, although many standing dead oaks remain. Additionally, Wilson et al. (1995) found that red-cockaded woodpecker densities were greater in plots that were thinned and burned compared to plots that had simply been thinned or left fire-suppressed in the Ouachita National Forest in Arkansas. However, these authors did not provide pre-treatment densities of red-cockaded woodpecker clusters, thus making it difficult to judge the efficacy of treatments, as these birds may have been absent from control and thinned plots prior to treatment application. The recent burning of our ULW® and felling/girdling plots may dramatically improve their suitability for red-cockaded woodpeckers. In addition to favorable habitat structure, this suitability may be linked to the positive relationships between arthropod density and biomass and measures of groundcover vegetation that result from repeated fires (Chapter 5).

Restoration treatments apparently did not adversely affect any of the other species of concern (Bachman's sparrow, northern bobwhite quail, blue grosbeak, and summer tanager). Any conclusions about Bachman's sparrow are limited because of its very low and spotty detection rates in restoration plots. Of interest, however, is that Bachman's sparrows remained undetected two years post-treatment in ULW® plots although they were present in these plots during pre-treatment sampling (Table 6.1). This species tends to breed early in the spring (see Baicich and Harrison 1997) relative to our survey period.

Although American kestrels were seen frequently in reference plots, they were infrequently detected in pre-treatment restoration plots despite the availability of grasshoppers (see Fig. 5.11 in Chapter 5), a preferred prey (Terres 1991). Because this species requires open habitat in

which to nest and hunt prey (Hoffman and Collopy 1988, Hamel 1992), we hypothesize increased detection rates for this species in 1998 and 1999 in felling/girdling and ULW[®] plots. The midstory of these plots has now been burned in addition to being treated. Burning of the relatively open felling/girdling plots may have a positive effect on kestrels through increased food supply (phytophagous insects such as grasshoppers) and a reduction in slash. The midstory of the ULW[®] plots continues to open up as the result of the toppling of standing dead oaks due to effects of herbicide, burning, and wind; thus improving their suitability for nesting and hunting. Burning would also be expected to increase food supply in these plots, again through an increase in the herbaceous ground component and concomitant increase in prey biomass. Some of the hotter burns observed to occur in both treatment types are likely to lead to increases in potential cavity sites that may benefit this and other species dependent on snag availability.

Winter Bird Foraging. Initial results of the winter 1996/97 season mainly reflect differences in bird-habitat associations and bird species niches. Bird species sympatric with longleaf pine such as red-cockaded woodpecker and brown-headed nuthatch foraged almost exclusively on longleaf pine, as did the pine warbler, noted for its affinity for pines. The seven other species presented here are more commonly associated with deciduous or mixed deciduous-coniferous forest (Morse 1967, Ehrlich et al. 1988, Hamel 1992). The hardwood component of longleaf pine sandhills habitat is important to such species, for which sandhills are suitable but not optimal habitats (Hamel 1992).

Observations of substrate use and foraging maneuvers reflect differences in bird foraging guilds. Woodpeckers commonly forage for insects by probing into tree trunks (Hamel 1992), hence the high percentage of observations for the bole substrate for these species. The smaller downy woodpecker tends to forage on smaller substrates such as branches and twigs (Hamel 1992) and this was reflected in higher branch and twig use relative to the other woodpecker species. The brown-headed nuthatch, like the woodpeckers, also probes for as well as gleans insects, but its smaller size and greater agility allow it to better utilize canopy substrates such as branches and twigs (Morse 1967). This species also eats seeds from the cones in years of abundant seed crops (Morse 1967) such as 1996/97.

The ecologically similar brown-headed nuthatch and pine warbler occur together in longleaf pine habitats and compete for available food resources (Morse 1967, Nesbitt and Hetrick 1976). Niche separation of these two species on EAFB's sandhills appears to be in the greater use of branches by the nuthatches versus greater use of pine needle bundles by the pine warblers. They also foraged on hardwoods more than brown-headed nuthatches.

Between palm warbler and ruby-crowned kinglet, both winter residents only, the latter appeared more dependent upon hardwoods, using longleaf pine very little. Palm warbler used both hardwoods and pines fairly evenly, but sand pine was used more than longleaf pine. Sand pines tend to have low branches that a bush gleaner like the palm warbler would prefer for foraging. Ruby-crowned kinglet is also a bush gleaner, evidenced by their high use of leaves and twigs, mainly on yaupon and sand live oak.

That searching was the predominant foraging behavior observed attests to the difficulty of actually observing what the bird is doing and the great range within this foraging strategy between species such as the woodpeckers compared to the small songbirds. In most cases searching was defined as the bird's focusing its attention on the substrate in question. Searching by pine warblers connotes a rather different technique than that observed for woodpeckers such as the red-cockaded, however. The former species exhibits considerable head movement as it scans both the surface of the substrate it is foraging on and the surrounding substrates (including air since it was observed to hawk insects) while the latter's attention seems to be focused more on the substrate itself. In any event, classifying both species as generally searching was deemed sufficient to illustrate specific substrate use.

Greater observations of more specific foraging techniques for the woodpeckers was due in part to these species' greater observability, as they forage at a substantially slower rate than the other species. They are also highly detectable while foraging, the pecking action readily audible; hence, the high proportion of observations of this type.

ISSUES OF MANAGEMENT CONCERN

From the 1997 breeding season, we identified pine warbler and red-cockaded woodpecker as species sensitive to contrasting structural features of the longleaf pine habitat. Pine warblers responded strongly to a reduced and fallen midstory and a mature pine canopy, whereas red-cockaded woodpecker did not respond as strongly to hardwood reduction techniques. In addition to their specific breeding season responses, pine warblers have shown a very generalized winter foraging strategy and diet (Nesbitt and Hetrick 1976, Ehrlich et al. 1988, Hamel 1992). This species appears to tolerate fire-suppressed habitat for breeding (Wilson et al. 1995, this study), thus suggesting this species may better represent the whole habitat. For these reasons and because pine warbler is abundant enough to provide statistically sound numbers, it may be considered a good indicator species of rapid ecological change and management activities. These attributes are in contrast with the red-cockaded woodpecker, whose detection rates are often low outside of prime areas and show relatively unresponsive initial effects to treatment application due to social and ecologic factors.

Of considerably more importance to EAFB managers, however, may be the costs or benefits of different habitat restoration techniques to long-term species population levels rather than initial, perhaps short-lived effects. The processes of habitat succession accelerated by the managed conversion of longleaf pine-dominated sandhills from fire-suppressed to pyrogenic (fire-prone) should result in a bird community that is characteristic of this type of habitat. We understand relatively little about this long-term process in the southeastern U.S.

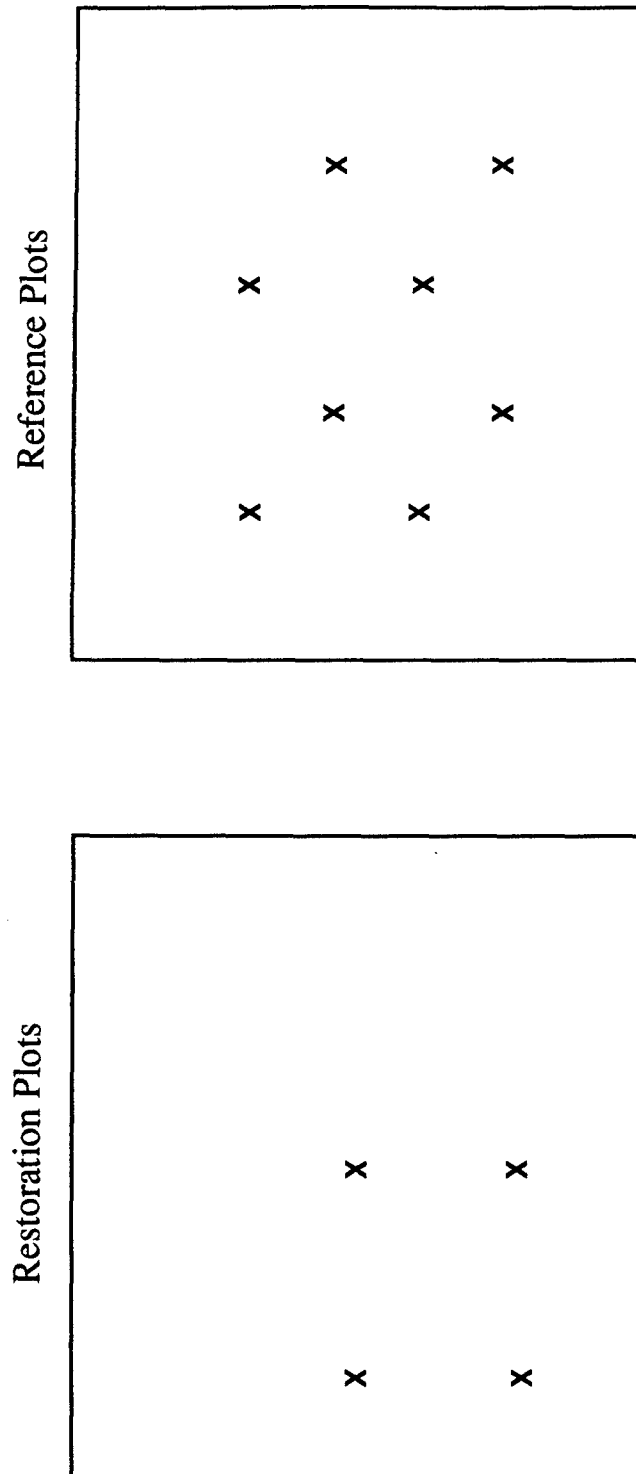


Fig. 6.1. Arrangement of bird sampling stations (X) on restoration and reference 81-ha (200-acre) plots. Due to randomized placement of stations, they were located approximately 200 m apart to minimize the possibility of recording the same individual during a survey. Stations are spaced along one plot edge (restoration plots) or centered in the plot (reference plots).

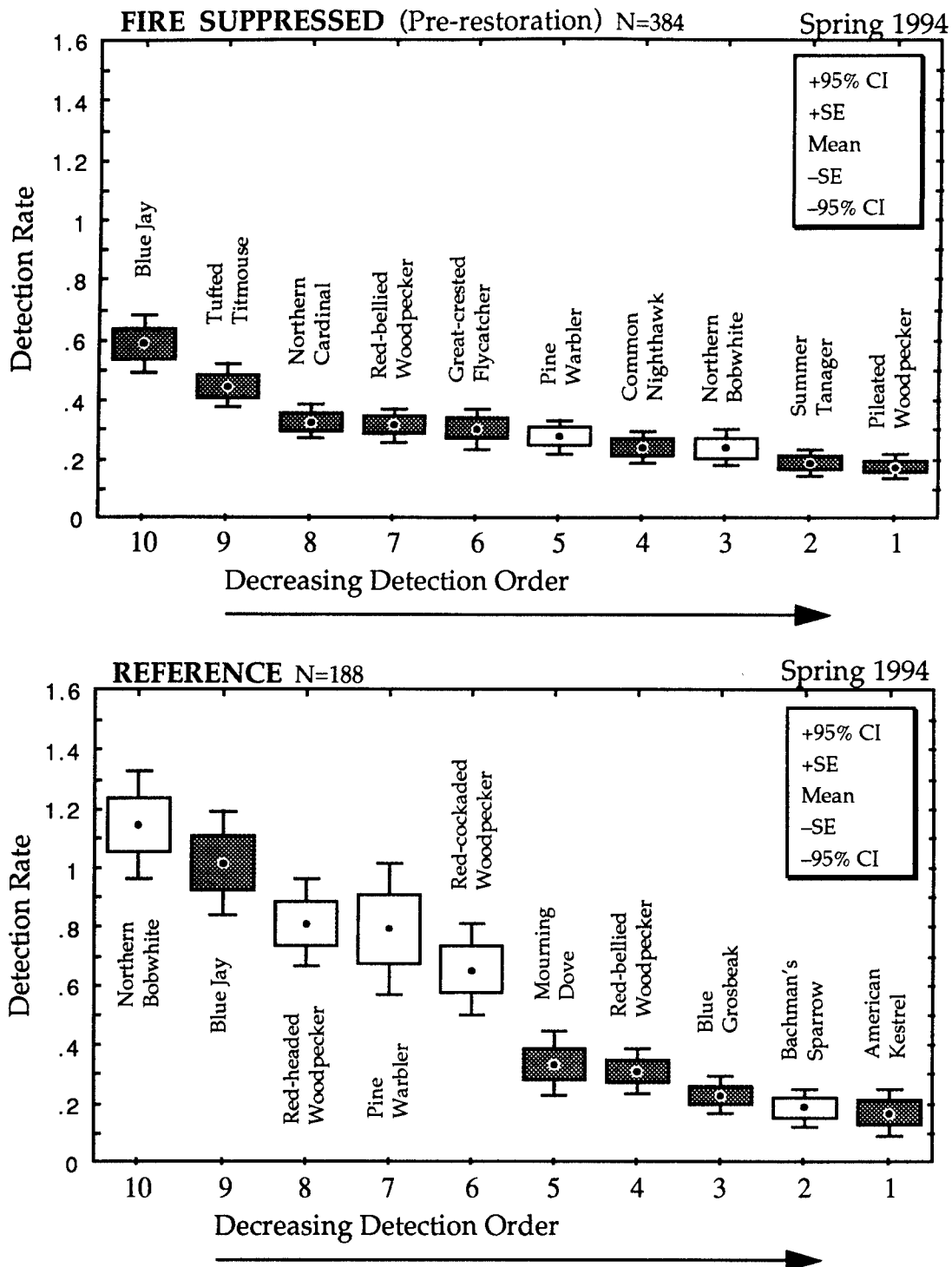


Figure 6.2. Fire-suppressed and reference avian community profiles for the 10 most frequently detected species on combined point counts from pre-treatment data sets for both habitat types. Open boxes represent pine-grassland associated species. Means (point), standard error (box), and 95% confidence intervals (range) are presented. Individual species values are not directly comparable between habitat types (see text).

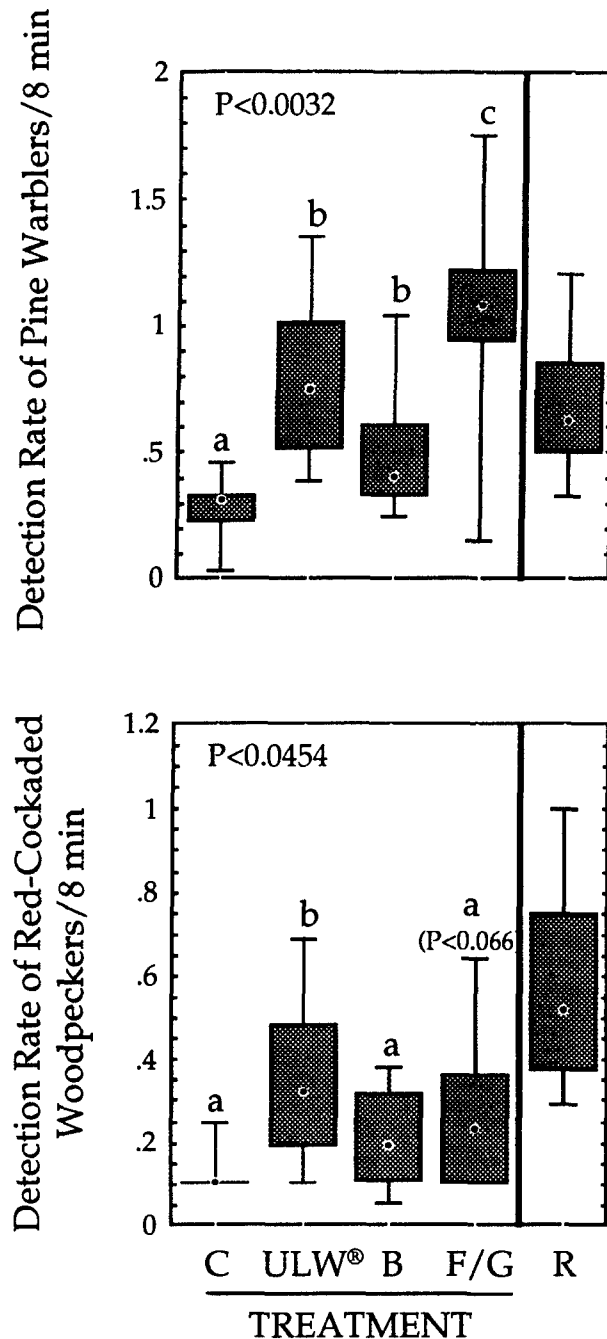


Fig. 6.3. Detection rates of pine warblers and red-cockaded woodpeckers in restoration and reference plots post-treatment (1995 and 1996). Detection rates were adjusted for restoration treatments only and estimated from pre-treatment values using ANCOVA. Center of box represents the median, upper and lower edges of box are the 25% and 75% quartiles, and error bars represent the minimum and maximum values. Significance probability is the test of the effects of the four restoration treatments, which do not include the R plots. Lowercase letters associated with error bars code for the three following independent contrasts: C vs. B, B vs. ULW®, and B vs. F/G. Different letters indicate significantly different means. Legend: B = burn; C = control; F/G = felling/girdling; R = reference; ULW® = herbicide.

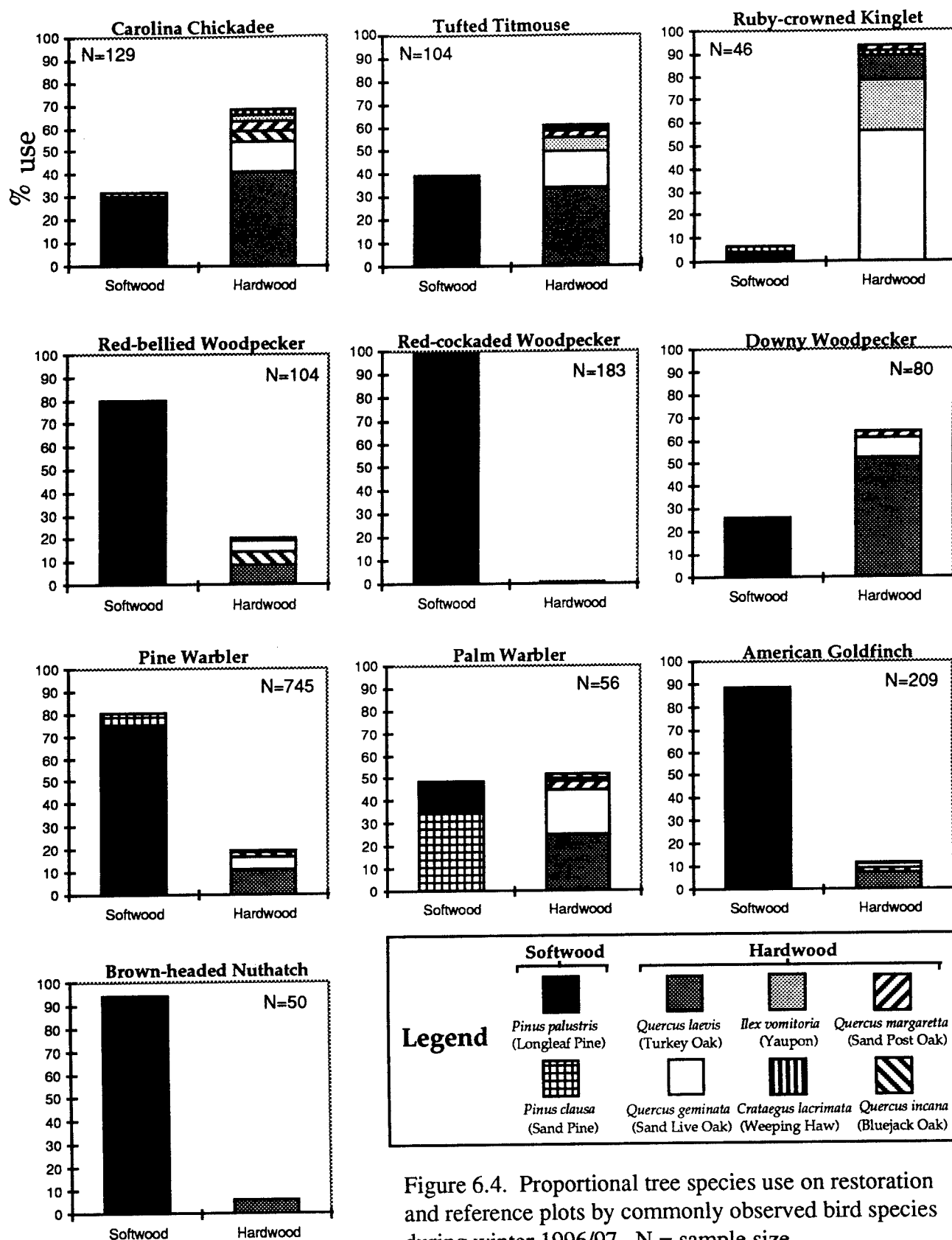


Figure 6.4. Proportional tree species use on restoration and reference plots by commonly observed bird species during winter 1996/97. N = sample size.

BREEDING AND WINTERING BIRDS

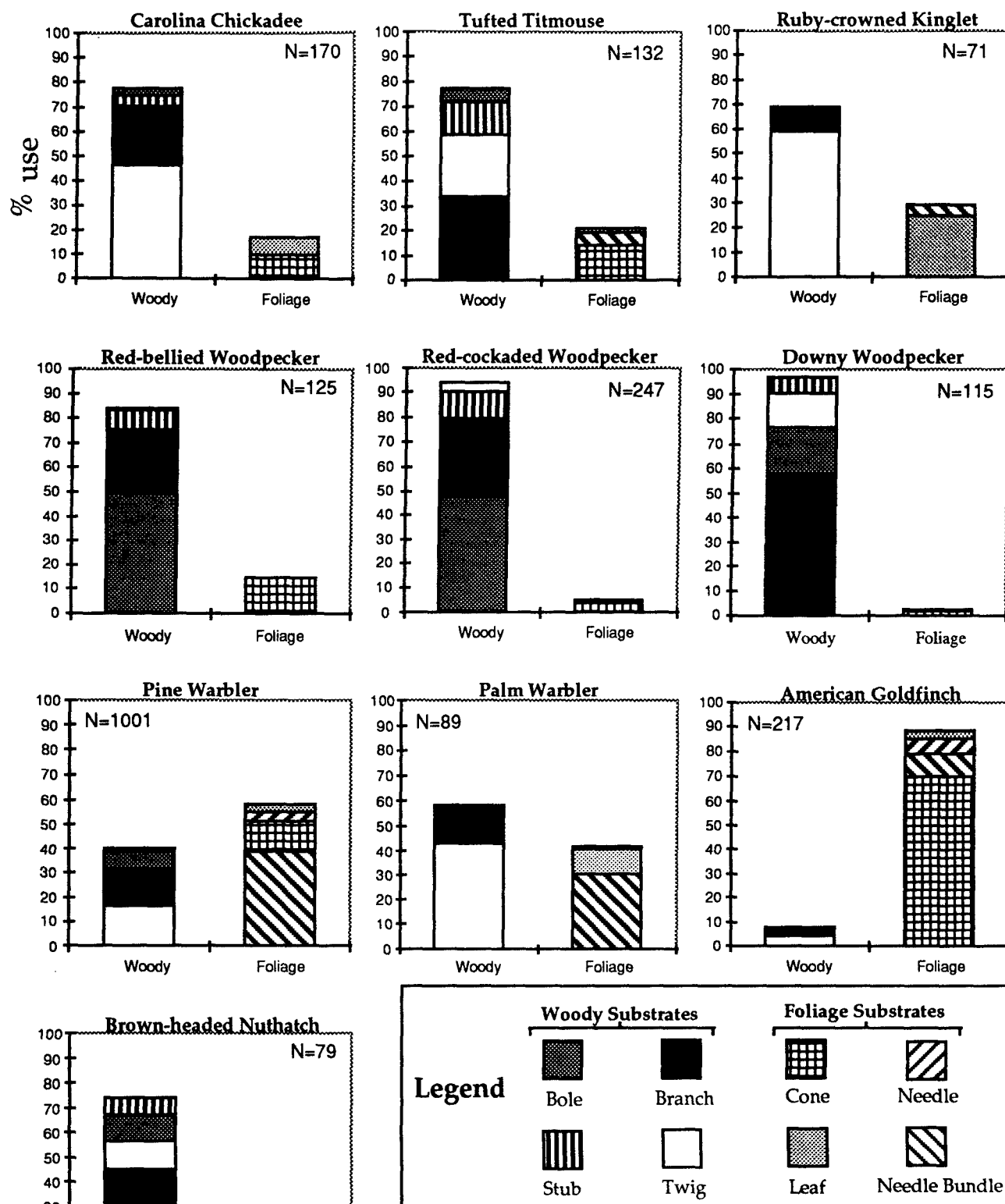


Figure 6.5. Proportional foraging substrate use on restoration and reference plots by commonly observed bird species during winter 1996/97. N = sample size.

BREEDING AND WINTERING BIRDS

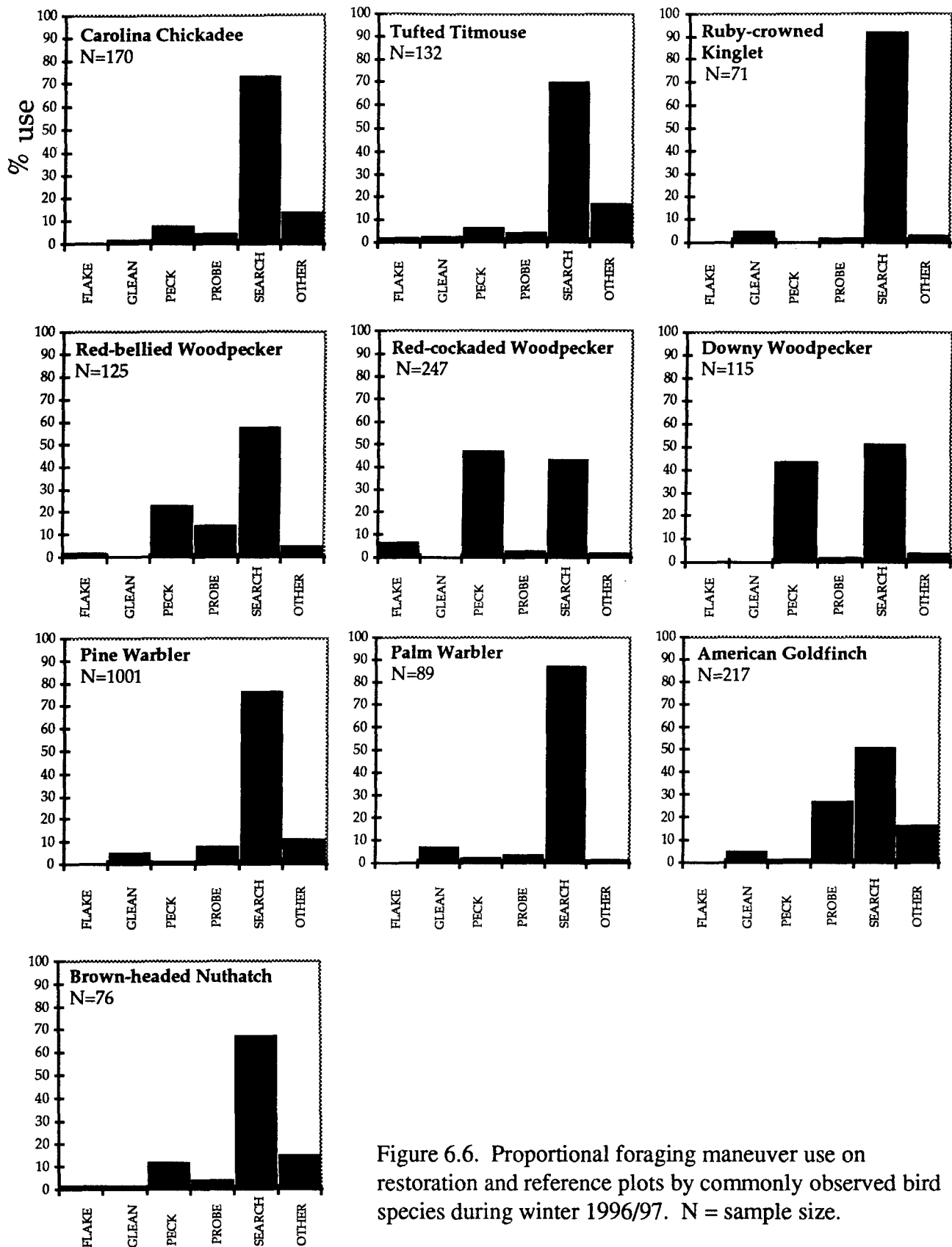


Figure 6.6. Proportional foraging maneuver use on restoration and reference plots by commonly observed bird species during winter 1996/97. N = sample size.

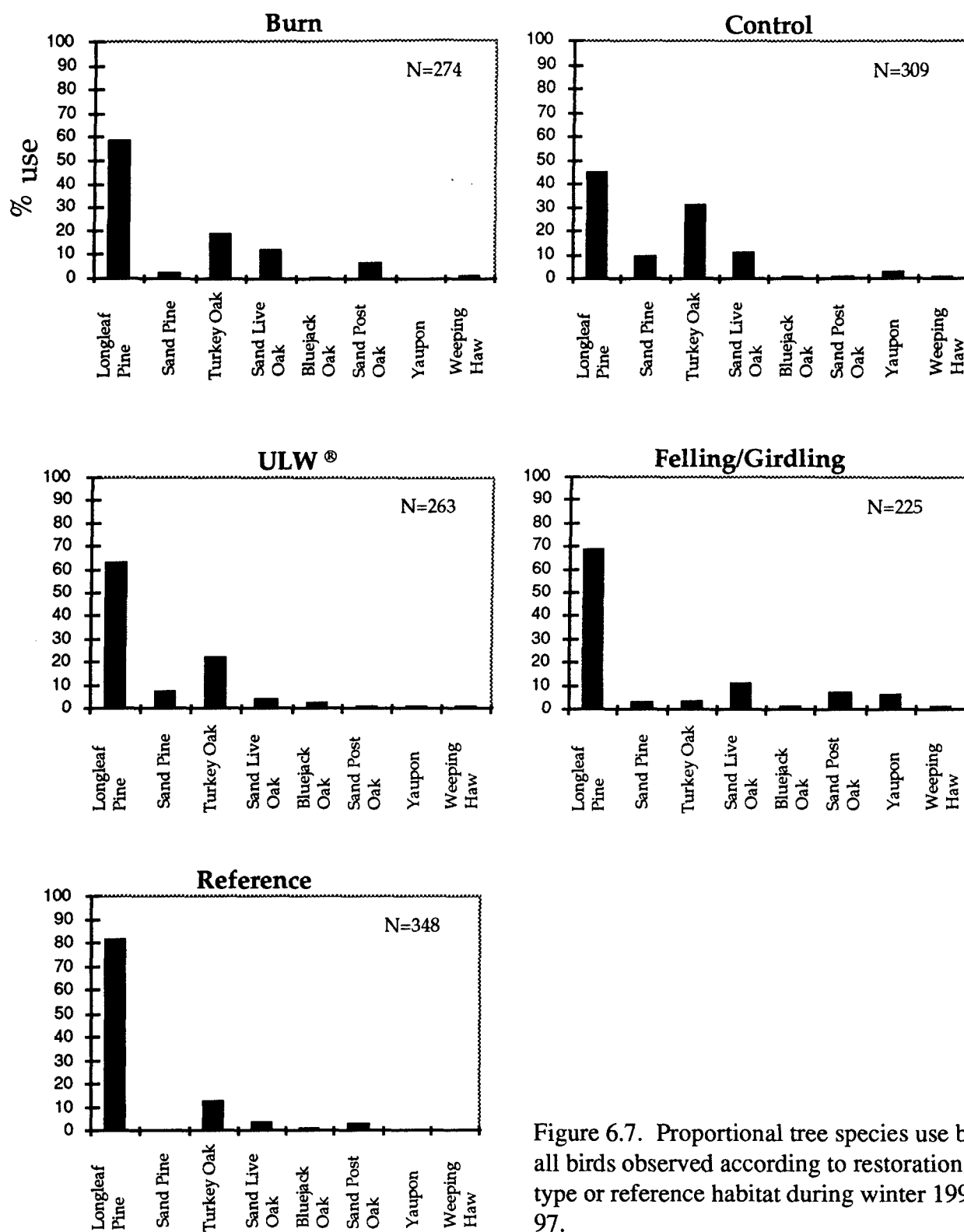


Figure 6.7. Proportional tree species use by all birds observed according to restoration type or reference habitat during winter 1996/97.

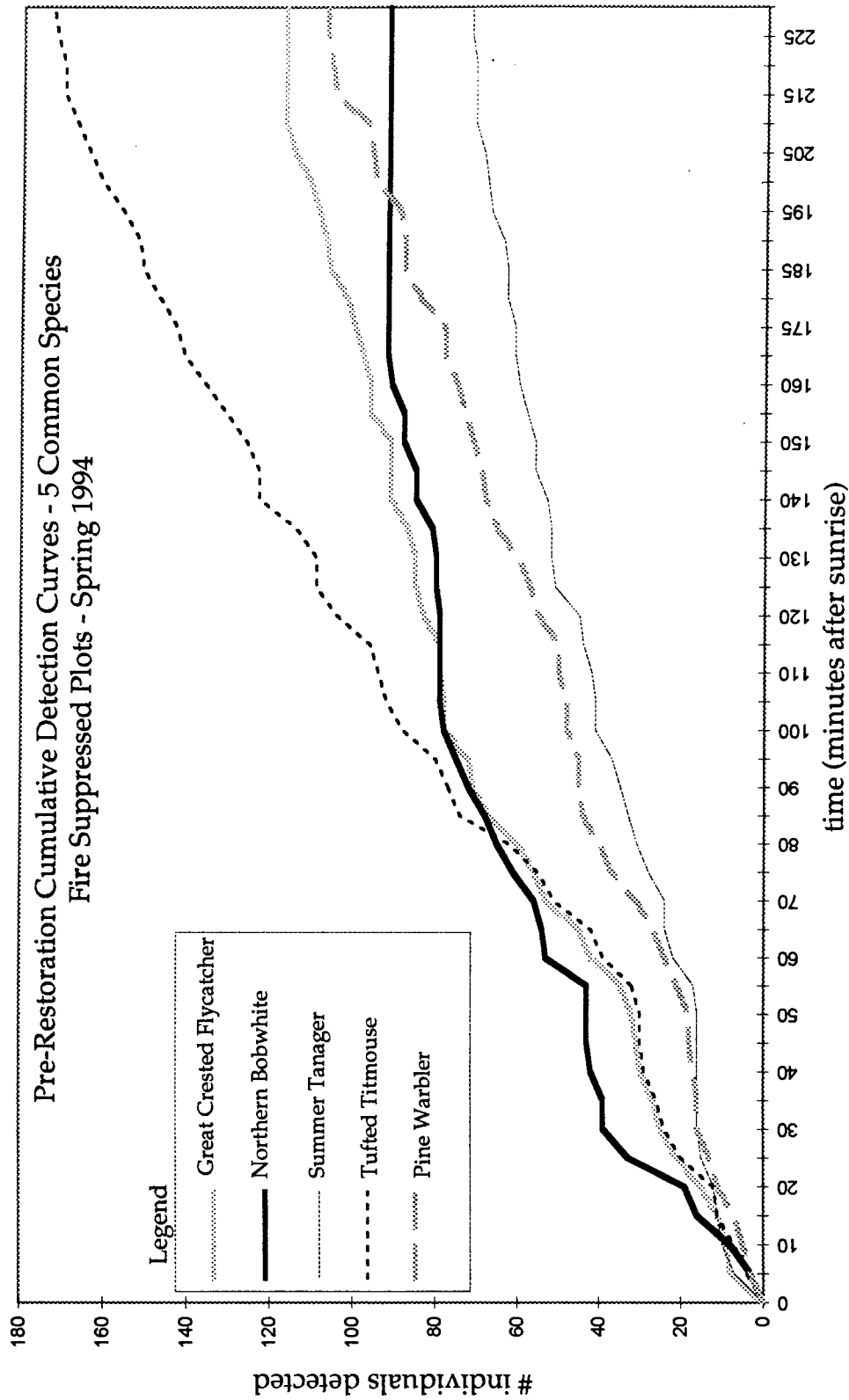


Fig. 6.8. Graphic illustration of change in spring 1994 detection rates for selected species over the course of the morning survey (all fire-suppressed point counts combined).

Table 6.1. Detection rates (± 1 standard error) (detections/8 min) of the 19 more abundant or threatened and endangered breeding bird species sampled in 24, 81-ha (200-acre) restoration plots and 6, 81-ha reference plots at Eglin Air Force Base, Florida. Sample size = 6, 81-ha plots.

Species	Treatment				Reference
	Control	ULW ^a	Burn	Felling	
Spring 1994 (pre-treatment)					
Bachman's Sparrow	0.000 ± 0.000	0.063 ± 0.063	0.000 ± 0.000	0.031 ± 0.031	0.185 ± 0.047
Blue Grosbeak	0.083 ± 0.045	0.042 ± 0.021	0.031 ± 0.021	0.073 ± 0.025	0.226 ± 0.060
Brown-headed Nuthatch	0.010 ± 0.010	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.106 ± 0.039
Blue Jay	0.750 ± 0.154	0.521 ± 0.121	0.427 ± 0.129	0.656 ± 0.187	1.013 ± 0.159
Carolina Chickadee	0.146 ± 0.042	0.104 ± 0.035	0.125 ± 0.046	0.083 ± 0.026	0.032 ± 0.017
Carolina Wren	0.146 ± 0.085	0.031 ± 0.021	0.094 ± 0.039	0.146 ± 0.064	0.010 ± 0.010
Great Crested Flycatcher	0.521 ± 0.197	0.125 ± 0.054	0.313 ± 0.147	0.260 ± 0.080	0.031 ± 0.026
Hairy Woodpecker	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.021 ± 0.013	0.000 ± 0.000
Mourning Dove	0.083 ± 0.055	0.146 ± 0.064	0.260 ± 0.089	0.135 ± 0.059	0.333 ± 0.161
Northern Bobwhite Quail	0.198 ± 0.059	0.313 ± 0.111	0.177 ± 0.050	0.271 ± 0.130	1.133 ± 0.202
Northern Cardinal	0.521 ± 0.153	0.208 ± 0.088	0.271 ± 0.080	0.313 ± 0.072	0.073 ± 0.061
Northern Flicker	0.063 ± 0.023	0.135 ± 0.041	0.104 ± 0.062	0.073 ± 0.041	0.160 ± 0.049
Pine Warbler	0.260 ± 0.050	0.188 ± 0.072	0.344 ± 0.153	0.323 ± 0.063	0.797 ± 0.187
Pileated Woodpecker	0.271 ± 0.050	0.156 ± 0.048	0.156 ± 0.039	0.125 ± 0.070	0.052 ± 0.021
Red-bellied Woodpecker	0.271 ± 0.075	0.260 ± 0.101	0.302 ± 0.073	0.438 ± 0.105	0.313 ± 0.034
Red-cockaded Woodpecker	0.021 ± 0.021	0.208 ± 0.147	0.167 ± 0.120	0.104 ± 0.068	0.651 ± 0.129
Summer Tanager	0.167 ± 0.062	0.333 ± 0.188	0.094 ± 0.045	0.156 ± 0.048	0.124 ± 0.054
Tufted Titmouse	0.583 ± 0.120	0.260 ± 0.076	0.417 ± 0.103	0.542 ± 0.159	0.138 ± 0.030
Yellow-billed Cuckoo	0.063 ± 0.023	0.083 ± 0.031	0.125 ± 0.065	0.083 ± 0.050	0.037 ± 0.021
Spring 1997 (second year post-treatment)					
Bachman's Sparrow	0.000 ± 0.000	0.000 ± 0.000	0.111 ± 0.082	0.014 ± 0.014	0.076 ± 0.042
Blue Grosbeak	0.000 ± 0.000	0.028 ± 0.028	0.139 ± 0.082	0.097 ± 0.062	0.042 ± 0.022
Brown-headed Nuthatch	0.000 ± 0.000	0.097 ± 0.069	0.000 ± 0.000	0.167 ± 0.086	0.146 ± 0.069
Blue Jay	0.500 ± 0.057	0.778 ± 0.119	0.458 ± 0.152	0.556 ± 0.163	0.660 ± 0.090
Carolina Chickadee	0.167 ± 0.078	0.153 ± 0.090	0.208 ± 0.088	0.292 ± 0.088	0.056 ± 0.021
Carolina Wren	0.083 ± 0.068	0.069 ± 0.045	0.028 ± 0.018	0.139 ± 0.035	0.007 ± 0.007
Great Crested Flycatcher	0.250 ± 0.114	0.236 ± 0.130	0.250 ± 0.089	0.306 ± 0.098	0.035 ± 0.017
Hairy Woodpecker	0.042 ± 0.028	0.069 ± 0.045	0.069 ± 0.045	0.194 ± 0.093	0.014 ± 0.014
Mourning Dove	0.139 ± 0.067	0.222 ± 0.073	0.250 ± 0.096	0.181 ± 0.059	0.139 ± 0.048
Northern Bobwhite Quail	0.181 ± 0.055	0.292 ± 0.088	0.347 ± 0.124	0.236 ± 0.095	0.583 ± 0.125
Northern Cardinal	0.542 ± 0.117	0.208 ± 0.093	0.236 ± 0.050	0.403 ± 0.095	0.083 ± 0.049
Northern Flicker	0.167 ± 0.061	0.208 ± 0.088	0.111 ± 0.051	0.292 ± 0.077	0.111 ± 0.043
Pine Warbler	0.250 ± 0.071	0.708 ± 0.200	0.597 ± 0.108	1.083 ± 0.216	0.708 ± 0.142
Pileated Woodpecker	0.097 ± 0.040	0.069 ± 0.033	0.083 ± 0.043	0.069 ± 0.026	0.021 ± 0.014
Red-bellied Woodpecker	0.264 ± 0.092	0.306 ± 0.115	0.403 ± 0.111	0.361 ± 0.035	0.424 ± 0.062
Red-cockaded Woodpecker	0.042 ± 0.042	0.431 ± 0.148	0.250 ± 0.139	0.264 ± 0.135	0.590 ± 0.120
Summer Tanager	0.139 ± 0.093	0.014 ± 0.014	0.167 ± 0.078	0.097 ± 0.069	0.076 ± 0.033
Tufted Titmouse	0.528 ± 0.088	0.444 ± 0.201	0.458 ± 0.144	0.528 ± 0.125	0.167 ± 0.048
Yellow-billed Cuckoo	0.014 ± 0.014	0.014 ± 0.014	0.028 ± 0.028	0.014 ± 0.014	0.007 ± 0.007

Table 6.2. Two-way analyses of covariance for tests of restoration treatments and pre-treatment effects on breeding bird detection rates from the spring 1997 sampling period in mixed hardwoods and longleaf pine forests at Eglin Air Force Base, Florida. Restoration treatments are growing season burn, application of ULW[®] herbicide, hand felling and girdling of hardwoods and sand pine, and no-treatment control. The experimental design is a complete randomized block design. The covariate is the pre-treatment data of the spring 1994. The error term is the mean square of the interaction of the block and restoration (block*restoration) effects. Bird species detection rates were $\log(\sqrt{[X + 0.5]})$ transformed to stabilize variances.

Source	Sum of squares	t-value	df	p-value
Blue Grosbeak				
Block	0.0078		5	
Restoration	0.0042		3	0.3185
Pre-treatment	0.0004		1	0.5000
Error	0.0097		14	
Blue Jay				
Block	0.0248		5	
Restoration	0.0092		3	0.3244
Pre-treatment	0.0009		1	0.5000
Error	0.0468		14	
Carolina Chickadee				
Block	0.0043		5	
Restoration	0.0058		3	0.0644
Pre-treatment	0.0130		1	0.0025
Error	0.0151		14	
Carolina Wren				
Block	0.0051		5	
Restoration	0.0022		3	0.5713
Pre-treatment	0.0000		1	0.5000
Error	0.0073		14	
Great Crested Flycatcher				
Block	0.0372		5	
Restoration	0.0010		3	0.9588
Pre-treatment	0.0000		1	0.5000
Error	0.0219		14	
Hairy Woodpecker (no-pre- treatment data)				
Block	0.0075		5	
Restoration	0.0025		3	0.4599
Error	0.0120		15	
Mourning Dove				
Block	0.0094		5	
Restoration	0.0007		3	0.9193
Pre-treatment	0.0006		1	0.5000
Error	0.0196		14	
Northern Bobwhite Quail				
Block	0.0116		5	
Restoration	0.0031		3	0.7642
Pre-treatment	0.0022		1	0.5000
Error	0.0281		14	
Northern Cardinal				
Block	0.0223		5	

Table 6.2. Continued.

Source	Sum of squares	t-value	df	p-value
Restoration	0.0160		3	0.0740
Pre-treatment	0.0002		1	0.5000
Error	0.0238		14	
Northern Flicker				
Block	0.0148		5	
Restoration	0.0059		3	0.4761
Pre-treatment	0.0000		1	0.5000
Error	0.0168		14	
Pine Warbler				
Block	0.0024		5	
Restoration	0.0641		3	0.0032
Pre-treatment	0.0191		1	0.1000
Error	0.0643		14	
Contrast				
C vs B†		-1.5546	1	0.0236
B vs F/G		-2.0184	1	0.0272
B vs U		-0.9680	1	0.1919
Pileated Woodpecker				
Block	0.0015		5	
Restoration	0.0003		3	0.9191
Pre-treatment	0.0025		1	0.0250
Error	0.0046		14	
Red-bellied Woodpecker				
Block	0.0094		5	
Restoration	0.0025		3	0.8637
Pre-treatment	0.0064		1	0.2000
Error	0.0351		14	
Red-cockaded Woodpecker				
Block	0.0187		5	
Restoration	0.0088		3	0.0454
Pre-treatment	0.0174		1	0.0025
Error	0.0160		14	
Contrast				
C vs B		-0.5338	1	0.3616
B vs F/G		-1.0340	1	0.0661
B vs U		-2.0704	1	0.0017
Summer Tanager				
Block	0.0117		5	
Restoration	0.0046		3	0.8447
Pre-treatment	0.0002		1	0.5000
Error	0.0202		14	
Tufted Titmouse				
Block	0.0283		5	
Restoration	0.0004		3	0.9872
Pre-treatment	0.0097		1	0.2000
Error	0.0555		14	

† Abbreviations of treatments: B = burn; C = control; F/G = felling/girdling; U = ULW®.

BREEDING AND WINTERING BIRDS

Table 6.2. Continued.

Source	Sum of squares	t-value	df	p-value
Yellow-billed Cuckoo				
Block	0.0007		5	
Restoration	0.0001		3	0.9958
Pre-treatment	0.0001		1	0.5000
Error	0.0016		14	

7. CONCLUSIONS AND MANAGEMENT IMPLICATIONS

We have discussed the management implications of results in previous chapters. The purpose of this section is to bring the management issues arising from each chapter together while distinguishing between treatments and metrics that measure treatment effects. We stress again that we are presenting initial results from a five-year project. This report primarily focuses on the ecological responses to treatments prior to fuel reduction burns in 12 plots that were implemented during winter and spring 1997, thus these conclusions and our assessment of management implications may change. We chose to present our findings in an order that reflects the potentially increasing sensitivity of general taxa to local habitat modifications (see Chapter 1 and Gordon et al. 1997).

MODEL VALIDATION

Eglin managers and cooperating scientists created a simple conceptual model of sandhill ecosystem degradation and recovery (Fig. 7.1; Provencher et al. 1997). In this model, the overall model "space" captured the observed dynamic range of possible sandhill states or starting conditions (as expressed by alternative community structure and composition of forest patches or stands) observed on Eglin over time. These different starting conditions are classified primarily on the basis of whether old growth longleaf pine (*Pinus palustris*) individuals (>150 years old) were present, the presence of a codominant mid- or overstory of hardwoods and/or sand pine, and the extent to which understories were dominated by only a few, primarily ruderal plant species. The different starting conditions are known or are hypothesized to be the result of past anthropogenic soil disturbance and fire suppression. Similarly, each of these different sandhill patches are assumed to have different trajectories across model space and time depending on a combination of starting conditions, management intervention type, and biological recovery processes (e.g., plant succession, nutrient flux).

Previous reports (Provencher et al. 1996 and 1997) summarized the starting conditions of "treatment" plots and "reference" plots in both the hardwood removal experiment and the sand pine removal study. This report specifically focused on the response of biological variables in treatment plots to initial treatments (as depicted in the lower middle and right of the model). The trajectories in the model depict the relative differences in the generalized biological response to the various treatments. Empirical evidence and experience suggest that if left untreated and in the absence of fire, each of the different starting conditions will move down and, over time, to the lower right of the model. If treated, each model state is assumed to be set on a unique trajectory, depending on the degree of soil disturbance and the season and frequency of fire. A chronosequence study on Eglin suggested that the time of recovery from a severely soil disturbed and fire suppressed plot may be >50 years (Provencher et al. 1996). The remainder of this summary provides preliminary evidence in support of this general model and suggests both trajectories for certain aspects of the sandhill community as well as potential indicators of biological response.

MONITORING RESULTS AND TREATMENT EFFICACY

Soils. Three important results were revealed by soil chemistry and texture analyses from upper soil horizons. First, the relationship between percent silt and the depth of the argillic layer in Troup soils was not significant. Second, soil texture had more influence on tree abundance measures and groundcover vegetation measures than soil chemistry during the pre-treatment phase of our sampling. Third, percent silt was positively and significantly correlated to plant species richness. These results imply that the comparison of species richness from

sites with different silt contents should be made after the effect of silt on plant species richness is statistically removed.

Sand Pine Removal. Sand pine (*Pinus clausa*) removal will change plant community composition. Ruderal species will likely respond to soil disturbance as indicated by increases of plant species, low panic grasses (*Dichanthelium* spp.) and broomsedge (*Andropogon virginicus*) two years post-removal (Table 7.1). More importantly, exotic species have invaded study plots after sand pine removal. We recommend that land managers monitor invasive species in other areas of EAFB receiving extensive soil disturbance. Because 78% of containerized longleaf pine seedlings planted in sand pine removal plots survived their first year with minimal seedbed preparation other than fire, we recommend further studies on low impact longleaf pine regeneration.

Restoration Study. We imposed treatments that produced a continuum between partially topkilled hardwoods (growing season burn), dead but standing hardwoods (ULW®), and dead and felled hardwoods (felling/girdling) (Table 7.2). Felling/girdling accomplished the most effective and greatest reduction of the midstory (hardwoods and sand pine) relative to the cheaper alternative of growing season burning. For the same approximate cost as felling/girdling (Stephen Seiber, EAFB, *pers. comm.*), ULW® reduced the hardwood midstory less than felling/girdling (Table 7.2). Since other forms of hexazinone (Pronone® or brushbullet) are even less efficient at killing oaks than ULW® and are more labor intensive (Berish 1996), we believe that felling/girdling achieved the short-term management goal of reducing hardwood dominance best. In addition, on the basis of increased graminoid and forb (legume and non-legume) cover and density, felling/girdling would be favored over ULW®.

During the first spring post-treatment in 1996, arthropod density and biomass increased more in growing season burn plots than in any other treatment (Table 7.3). Felling/girdling caused the second greatest increase in biomass. Grasshoppers, which represented the majority of the sampled arthropod biomass, many leafhoppers and planthoppers, and moths achieved their highest densities in burn plots and, to a lesser extent, in felling/girdling plots (Table 7.3). Northern bobwhite quail, wild turkey, red-cockaded woodpeckers, and other wildlife feed heavily on arthropods, especially during the breeding season, so we suggest that managers could burn to increase arthropod availability. Because Hanula and Franzreb (1998) have shown that the majority of arthropods below the longleaf pine canopy that are prey to red-cockaded woodpecker disperse between the forest floor and the tree bole, the incentive to burn is high.

For the red-cockaded woodpecker, which is an important species of concern, all treatments showed an increase in detection rates for 1997 (Fig. 6.3). Burning alone and once was not sufficient to enhance their numbers compared to ULW® and, perhaps felling/girdling. Restoration burns produced this nonsignificant effect because many hardwoods were not topkilled in most plots. Pine warbler, which is not a species of concern, significantly responded to a reduced and, especially, fallen midstory (Fig. 6.3). Pine warbler, therefore, appeared to prefer a habitat structure most resembling the typical longleaf pine grassy landscape. There was no difference between burning and ULW® for pine warbler.

These treatments, however, are still in progress and making a final decision at this time on the most efficient treatment would be premature. Felling/girdling and ULW® plots were burned in March and April of 1997 for the purpose of reducing fuel loads. Felling/girdling followed by burns should result in a highly effective restoration effort, because fire should further stimulate plant species richness and herbaceous responses.

INDICATOR VARIABLES

We identified several taxa or variables that were most sensitive to treatment effects and, thus, to ecological perturbations. We generated a multitude of indicator variables from the

analysis of vegetation data. However, we will discuss here only those variables that responded significantly and that require minimal taxonomic and sampling efforts (Table 7.2). We learned that the reduction of hardwood midstory is more easily estimated by measuring canopy and midstory cover rather than by counting hardwoods and measuring their DBH and height. Because hardwood sampling is far more time-consuming than estimating cover with a spherical densiometer, we strongly suggest rapid canopy cover sampling as a better method to measure changes in hardwood encroachment. We have learned that the relationship between basal area of longleaf pine and increased tree mortality was less strong than was that between mortality and density. We suggest that if longleaf pine is to be tracked, density by size or age class should be used for ecologically driven management decisions rather than basal area. Basal area has the disadvantages of confounding density and DBH measurements into a single metric and of minimizing the importance of recruiting size classes.

Two plant metrics showed especially strong responses to treatments: the number of plant species and the density of low panic grasses (*Dichanthelium* spp.) (Table 7.2). Values for both of these metrics in 1996, decreased with treatment: burn, felling/girdling, control, and ULW®. Low panic grasses were sensitive to differences among the hardwood reduction techniques, which was not the case for most other variables. Plant species richness has been identified as a metric of ecological condition in other studies in this system (e.g., Walker and Peet 1983, Walker 1993). *Dichanthelium* is easily identified as a genus, and important because of its abundance and because low panic grasses provide year-round forage for many birds, including northern bobwhite quail (Grelen 1962). Species of *Dichanthelium*, however, are taxonomically complex and require taxonomic expertise for identification. Plant species richness should be determined by a botanist, because sandhill communities (degraded and pristine) tend to have a high level of plant richness. However, plant species richness and low panic grass density are not equivalent, in their response to fire. Low panic grasses were sensitive to both fire and soil disturbance (Table 7.1; see also chronosequence study in Provencher et al. 1996). To distinguish effects of soil disturbance from fire effects, sampling plant species richness would provide best information on soil disturbance effects.

Certain arthropod families responded significantly to the restoration treatments. Except for grasshoppers and braconid wasps, these families tended to be dominated by one morpho/species collected in high numbers by our sampling methods. Grasshoppers, sminthurid springtails, and flatid planthoppers were especially responsive to burning and were relatively common (Table 5.6). Grasshoppers can be visually counted and their length approximated *in situ* to estimate biomass.

Sminthurid springtails, while small (body length generally under 2 mm), are significant because of their high population densities. Springtail populations may number up to 100,000/m³ of surface soil, or literally millions per hectare (Borror et al. 1989). Sminthurid springtails have a characteristic body shape, so the family is easily identified. Moreover, >90% of sminthurid springtails sampled by our methods were identified as *Sminthurus carolinensis*. This species is apparently an excellent indicator of the effects of different techniques of hardwood midstory reduction and appears to be native to the southeast. In decreasing order of densities, springtails responded more strongly to burning, felling/girdling, control, and least to ULW®.

Nearly a dozen related families of planthoppers were sampled by our methods, some of which appeared to be very similar to each other. *Metcalfa pruinosa* was the only species in the family Flatidae that we sampled. This is a widespread species in the U.S. with a wide variety of plant hosts, so its positive response to burning versus other treatments is likely due to a complex set of factors.

Braconid wasps and dance flies are families that occurred in high numbers and responded decisively to felling/girdling. Braconid wasps are a complex family of parasitoids, whose populations will be tied into those of the hosts.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Among birds, pine warblers were sensitive to vertical habitat structure, were capable of differentiating among different hardwood reduction techniques, and, importantly, this species was common. In other words, pine warblers would be an indicator of reduced hardwood encroachment.

Evaluation of treatment success remains premature, because treatment application has continued into 1997, and we primarily reported here on results that were not affected by this latter change. We suggested that felling/girdling achieved the best primary restoration goal of midstory hardwood reduction compared to growing season burn and ULW®. Felling/girdling had many positive impacts also shared by other treatments. While stimulating arthropod biomass and plant species richness, growing season burns alone were least effective for rapid midstory reduction.

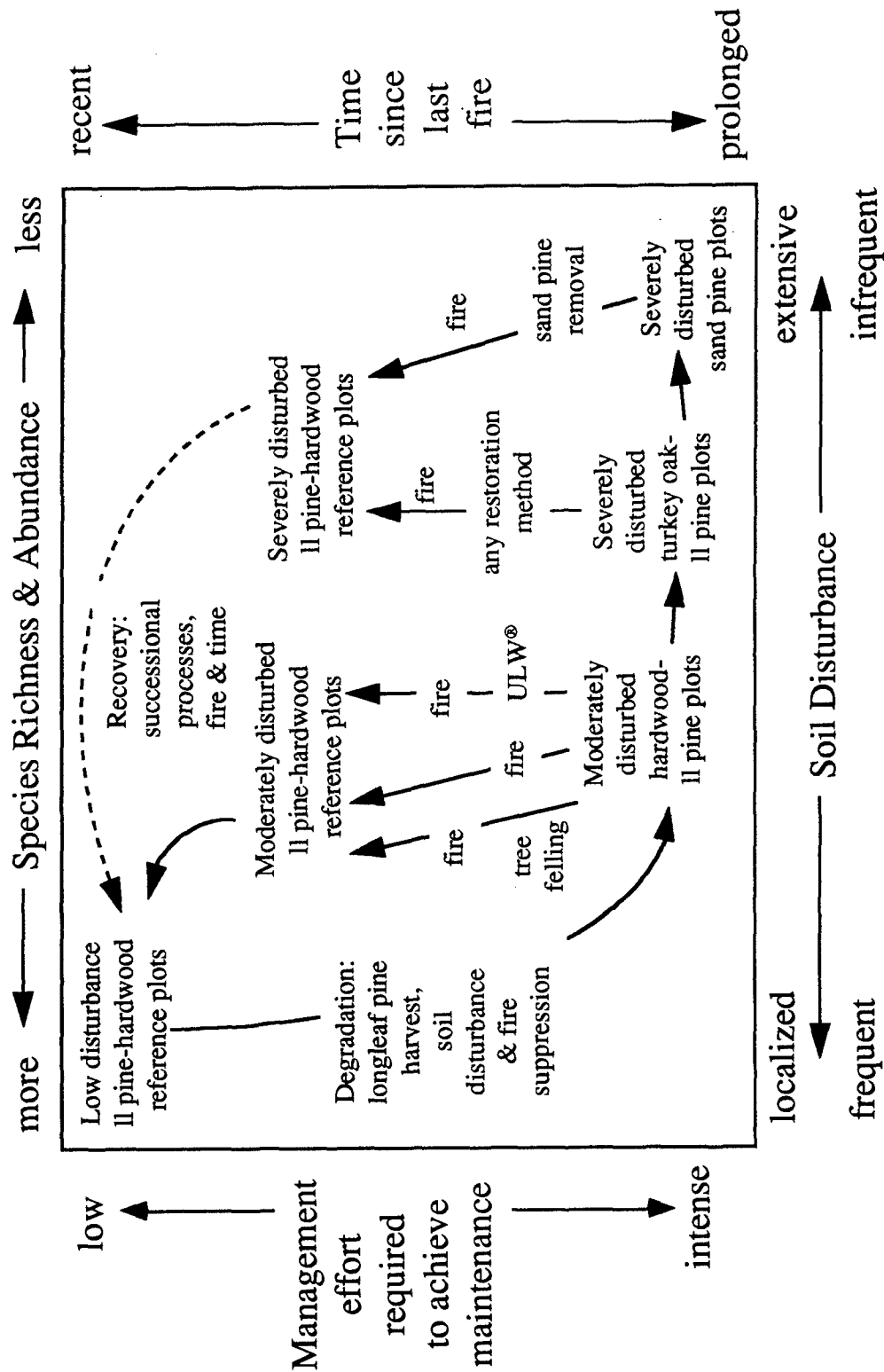


Fig. 7.1. Model of sandhill disturbance and recovery. Arrows indicate processes; their lengths are not proportional to time. Abbreviation: 11 pine = longleaf pine.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Table 7.1. Temporal vegetation changes since pre-treatment sampling in response to sand pine removal (1994-1996). Change in variable level include the change from pre-removal condition. Removal of sand pine was conducted from January 1995 to August 1995.

Variable	Increased	Decreased	Increasing after initial decline	No change
Plant species richness			X	
Florida spurge	X			
Low panic grasses	X			
Sand live oak	X			
Wiregrass	X			
Dwarf huckleberry		X		
Sand pine		X		
Broomsedge			X	
Catbrier			X	
Gopher apple			X	
Little bluestem			X	
Pineland hoary-pea			X	
Florida milk-pea				X

Table 7.2. Summary of significant fall 1995 and fall 1996 (post treatment) effects of hardwood reduction techniques on plant and tree variables. Adjusted values from each treatment were ranked from highest to lowest. Inequality signs are only presented for significant contrasts. The “?” sign indicates an uncertain outcome for an untested contrast. Pre-treatment effects were factored out of these summary results.

Variable	Fall 1995	Fall 1996
	Highest \leftrightarrow Lowest	Highest \leftrightarrow Lowest
Canopy and midstory structure and composition		
Proportion of canopy cover	$C > B = ULW^* > F/G^\dagger$	$C = B = ULW^* = F/G$
Longleaf pine		
Density	$C = ULW^* = F/G > B$...‡
Basal area	$ULW^* = F/G = B = C$	...
Sand live oak		
Density	$C > B = ULW^* > F/G$	...
Basal area	$B > C = ULW^* = F/G$	...
Turkey oak		
Density	$C > B = ULW^* > F/G$	...
Basal area	$C > B > ULW^* > F/G$	...
Proportion of cover of understory plant and woody residue		
Graminoids	$C = B = F/G > ULW^*$	$ULW^* > B = F/G > C$
Forbs	$B > ULW^* = F/G = C$	$ULW^* = B = F/G = C$
Fine litter	$ULW^* = F/G ? C > B$	$ULW^* = F/G ? C > B$
Woody species	$C > B = F/G > ULW^*$	$B > C = F/G ? ULW^*$
Woody litter	$F/G > C = ULW^* > B$	$F/G > B > ULW^* > C$
Density of understory plant species		
Plant species richness	$B = C = F/G = ULW^*$	$B > F/G = C = ULW^*$
Graminoids	$C > F/G = ULW^* = B$	$B > C = F/G > ULW^*$
Longleaf pine juveniles	$ULW^* = C = F/G > B$	$ULW^* = C = F/G > B$
Trees (<1.4 m high)	$F/G = B > C > ULW^*$	$B = ULW^* = C > F/G$
Woody vines	$C ? ULW^* > B = F/G$	$C = ULW^* = F/G = B$
Gopher apple	...§	$F/G > B = C > ULW^*$
Lopsided Indian grass	...	$ULW^* > F/G = B = C$
Low panic grasses	...	$B > F/G > C > ULW^*$
Pineywoods dropseed	...	$C > F/G = B > ULW^*$
Gray's beakrush	...	$C = B = F/G > ULW^*$
Wireweed	...	$C = F/G > ULW^* = B$
Yellow stargrass	...	$ULW^* > B = C = F/G$

† Treatments: B = burn; C = control; F/G = felling/girdling; ULW^* = herbicide.

‡ ... = trees not sampled during the winter 1996/1997.

§ ... = data not presented because treatment application immediately preceded sampling, and species had not experienced a full reproductive cycle in response to treatments.

Table 7.3. Summary of significant post-treatment effects of hardwood reduction techniques on arthropod family and morphospecies densities during spring 1996. Adjusted values measured in each treatment are ranked from highest to lowest. Inequality signs are only presented for significant contrasts. The “?” sign indicates an uncertain outcome for an untested contrast. Pre-treatment effects were factored out of these summary results.

Taxon	Density
	Highest ↔ Lowest
Flatid planthoppers	B > ULW [®] = F/G = C [†]
Grasshoppers	B > F/G = ULW [®] ? C
Phlaeothripid thrips	B = F/G = ULW [®] = C
Sminthurid springtails	B > F/G = C = ULW [®]
<i>Sminthurus carolinensis</i>	B > F/G = C = ULW [®]
Sampled biomass [‡]	B > F/G = ULW [®] ? C
<i>Metcalfa pruinosa</i>	B > C = ULW [®] = F/G
Leaf beetles	C ? B ? F/G ? ULW [®]
Dance flies	F/G > B = C = ULW [®]
Braconid wasps	F/G = B = C = ULW [®]
Empidid #1	F/G > ULW [®] = B = C
<i>Erythroneura</i> spp.	F/G > B > ULW [®] = C
Psocids	ULW [®] = F/G > B = C
Clubionid spiders	ULW [®] > B = F/G = C

[†] Treatments: B = burn; C = control; F/G = felling/girdling; ULW[®] = herbicide.

[‡] Sampled biomass was the sum of grasshopper biomass, which represented >90% of total biomass, adult moth biomass (see densities among treatments in Table 5.2), and biomass of most planthoppers and leafhoppers.

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APPENDIX A

Plant Species Observed in Restoration, Reference, and Sand Pine Removal Plots (1994-1996)

Checklist of all plant taxa encountered in restoration, reference, and sandpine removal plots at Eglin Air Force Base from 1994-1996 (Provencher et al. 1996 and 1997, Rodgers and Provencher, *in press*).

Taxa are arranged into the three following sections: pteridophytes, gymnosperms, and angiosperms. Within each group, the taxa are arranged alphabetically by family, genera, and species. Common names are included to aid the Eglin land managers.

Nomenclature for this checklist follows primarily Clewell (1985), Godfrey (1988), and Godfrey and Wooten (1979, 1981). On a few occasions, more recent taxonomic treatments were followed and the name referenced in Clewell is preceded by an *Sy* (synonym). References employed outside of Clewell are mainly in the Gramineae and Leguminosae families and include: Anderson (1988), Hall (1978), Isley (1990), Lelong (1986), Peet (1993). Common names were derived from a variety of sources outside of Clewell's text and include: Bell and Taylor (1982), Grelan and Duvall (1966), Hall (1993), Kindell et al. (1997), Taylor (1992) and an unpublished list (A. Gholson, Tall Timbers Research Station).

PTERIDOPHYTES **(FERNS AND FERN ALLIES)**

POLYPODIACEAE

Pteridium aquilinum

Bracken Fern

SELAGINELLACEAE

Selaginella arenicola

Sand Spikemoss

GYMNOSPERMS

PINACEAE

Pinus clausa

Sand Pine

P. elliotii

Slash Pine

P. palustris

Longleaf Pine

MONOCOTS

AGAVACEAE

Yucca flaccida

Weak-leaf Yucca

COMMELINACEAE

Commelina erecta

Erect Dayflower

Tradescantia hirsutiflora

Hairy Spiderwort

CYPERACEAE

Bulbostylis barbata

Watergrass

B. capillaris

Dense-tuft Hairsedge

B. ciliatifolia

Hair-like Bulbostylis

B. warei

Ware's Hairsedge

Carex tenax

Persistent Sedge

Cyperus filiculmis

Slender Flatsedge

<i>C. globulosus</i>	Globose Flatsedge
<i>C. retrofractus</i>	Reflexed Flatsedge
<i>C. retrorsus</i>	Retorse Flatsedge
<i>Rhynchospora fascicularis</i>	Fasciculate Beakrush
<i>R. grayi</i>	Gray's Beakrush
<i>R. megalocarpa</i>	Large-fruited Beakrush
<i>R. plumosa</i>	Plumed Beakrush
<i>Scleria ciliata</i>	Fringed Nutrush
ERIOCAULACEAE	
<i>Lachnocaulon beyrichianum</i>	Southern Bogbutton
GRAMINEAE (POACEAE)	
<i>Andropogon gerardii</i>	Big Bluestem
<i>A. gyrans</i>	Elliott's Bluestem
<i>A. ternarius</i>	Silver Bluestem
<i>A. virginicus</i>	Broomsedge
<i>Anthaenantia villosa</i>	Green Silkyscale
<i>Aristida beyrichiana</i> Sy = <i>A. stricta</i>	Wiregrass
<i>A. condensata</i>	Big Threeawn
<i>A. lanosa</i>	Woollysheat Threeawn
<i>A. longespica</i>	Slimspike Threeawn
<i>A. mohrii</i>	Mohr's Threeawn
<i>A. purpurescens</i>	Arrowfeather
<i>A. simpliciflora</i>	Chapman's Threeawn
<i>Arundinaria gigantea</i>	Cane
<i>Cenchrus incertus</i>	Coast Sandspur
<i>Chloris petraea</i> Sy = <i>Eustachys petraea</i>	Finger Grass
<i>Ctenium aromaticum</i>	Toothache Grass
<i>Danthonia sericea</i>	Silky Wild Oat-Grass
<i>Dichanthelium aciculare</i>	Needle-leaf Panic Grass
<i>D. acuminatum</i>	Pointed-tip Panic Grass
<i>D. angustifolium</i> Sy = <i>D. dichotomum</i>	Narrow-leaf Panic Grass
<i>D. chamaelonche</i> Sy = <i>D. dichotomum</i>	
<i>D. commutatum</i>	Variable Panic Grass
<i>D. consanguineum</i>	Blood Panic Grass
<i>D. dichotomum</i>	Forked Panic Grass
<i>D. ensifolium</i>	
Sy = <i>D. dichotomum</i> var. <i>ensifolium</i>	
<i>D. oligosanthos</i>	Heller's Panic Grass
<i>D. ovale</i>	Egg-leaf Panic Grass
<i>D. portoricense</i> Sy = <i>D. sabulorum</i>	Puerto Rico Panic Grass
<i>D. ravenelii</i>	Ravenel's Panic Grass
<i>D. sphaerocarpon</i>	Round-seed Panic Grass
<i>D. strigosum</i>	Fringed Panic Grass
<i>D. tenue</i> Sy = <i>D. dichotomum</i> var. <i>tenue</i>	White-edge Panic Grass
<i>Digitaria ciliaris</i>	Southern Crabgrass
<i>D. filiformis</i>	Slender Crabgrass
<i>Eragrostis refracta</i>	Coastal Lovegrass
<i>E. spectabilis</i>	Purple Lovegrass
<i>Eremochloa ophiuroides</i>	Centipede Grass
<i>Gymnopogon ambiguus</i>	Bearded Skeletongrass
<i>G. brevifolius</i>	Slim Skeletongrass
<i>Leptoloma cognatum</i>	Fall Witchgrass
<i>Muhlenbergia capillaris</i> Sy = <i>M. expansa</i>	Hairawn Muhly
<i>Panicum anceps</i>	Beaked Panicum

<i>P. verrucosum</i>	Warty Panicum
<i>P. virgatum</i>	Switchgrass
<i>Paspalum bifidum</i>	Pitchfork Paspalum
<i>P. notatum</i>	Bahia grass
<i>P. setaceum</i>	Thin Paspalum
<i>Schizachyrium hirtiflorum</i>	Rufous Bluestem
<i>S. scoparium</i>	Little Bluestem
<i>S. tenerum</i>	Slender Bluestem
<i>Sorghastrum nutans</i>	Wood Grass
<i>S. secundum</i>	Lopsided Indian Grass
<i>Sphenopholis filiformis</i>	Longleaf Wedgescale
<i>Sporobolus clandestinus</i>	Hidden Dropseed
<i>S. junceus</i>	Pineywoods Dropseed
<i>Triplasis americana</i>	Perennial Sandgrass
<i>T. purpurea</i>	Purple Sandgrass
HYPOXIDACEAE	
<i>Hypoxis juncea</i>	Yellow Stargrass
IRIDACEAE	
<i>Iris verna</i>	Dwarf Iris
<i>Sisyrinchium nashii</i> Sy = <i>S. arenicola</i>	Blue-eyed Grass
JUNCACEAE	
<i>Juncus dichotomus</i>	Forked Rush
<i>J. marginatus</i>	Shore Rush
<i>J. scirpoides</i>	
LILIACEAE	
<i>Aletris aurea</i>	Late flowering Colic-root
<i>A. lutea</i>	Yellow Colic-root
<i>Allium canadense</i>	Wild Onion
ORCHIDACEAE	
<i>Spiranthes tuberosa</i>	Little Ladies'-tresses
PALMAE (ARECACEAE)	
<i>Serenoa repens</i>	Saw Palmetto
SMILACACEAE	
<i>Smilax auriculata</i>	Catbrier
<i>S. bona-nox</i>	Greenbrier
<i>S. glauca</i>	Wild Sarsaparilla
<i>S. pumila</i>	Sarsaparilla Vine
XYRIDACEAE	
<i>Xyris caroliniana</i>	Carolina Yellow-eyed Grass
<i>X. elliotii</i>	Elliott's Yellow-eyed Grass
<u>DICOTS</u>	
ACANTHACEAE	
<i>Ruellia caroliniensis</i>	Wild Petunia
ACERACEAE	
<i>Acer rubrum</i>	Red Maple
AMARANTHACEAE	
<i>Froelichia floridana</i>	Cottonweed
ANACARDIACEAE	
<i>Rhus copallina</i>	Winged Sumac
<i>Toxicodendron radicans</i>	Poison Ivy

ANNONACEAE

Asimina longifolia
A. parviflora
A. triloba

APOCYNACEAE

Amsonia ciliata

AQUIFOLIACEAE

Ilex ambigua
I. coriacea
I. decidua
I. glabra
I. opaca
I. vomitoria

ARISTOLOCHIACEAE

Aristolochia serpentaria

ASCLEPIADACEAE

Asclepias cinerea
A. humistrata
A. pedicellata
A. tuberosa
A. verticillata

BETULACEAE

Alnus serrulata

BIGNONIACEAE

Bignonia capreolata

BORAGINACEAE

Lithospermum carolinense
Onosmodium virginianum

CACTACEAE

Opuntia humifusa
O. pusilla

CAMPANULACEAE

Lobelia brevifolia
Wahlenbergia marginata

CAPPARACEAE

Polanisia tenuifolia

CARYOPHYLLACEAE

Minuartia caroliniana
Paronychia baldwinii
P. patula
Stipulicida setacea

CHRYSOBALANACEAE

Licania michauxii

CISTACEAE

Helianthemum carolinianum
H. corymbosum
Lechea mucronata
L. sessiliflora

COMPOSITAE (ASTERACEAE)

Ageratina aromatica
Ambrosia artemisiifolia
Aster adnatus
A. concolor
A. dumosus

Longleaf Pawpaw
 Small-fruited Pawpaw
 Dog Banana

Blue Dogbane

Sand Holly
 Sweet Gallberry
 Possum Haw
 Gallberry
 American Holly
 Yaupon

Snake Root

Short Hooded milkweed
 Sandhill Milkweed
 Savannah Milkweed
 Butterfly Weed
 Whorl-leaf Milkweed

Hazel Alder

Cross Vine

Carolina Puccoon
 False Gromwell

Sprawling Prickly Pear
 Small Prickly Pear

Short-leaf Lobelia
 Asiatic Bellflower

Pineland Catchfly

Pine-barrens Sandwort
 Baldwin's Whitlow-wort
 Spreading Whitlow-wort
 Wire Plant

Gopher Apple

Carolina Rock-rose
 Clustered Rock-rose
 Hairy Long-leaved Pinweed
 Narrow-leaved Pinweed

Wild Hoarhound
 Common Ragweed
 Adnate-leaved Aster
 Silvery Aster
 Bush Aster

<i>A. linariifolius</i>	Stiff-leaved Aster
<i>A. tortifolius</i>	White-topped Aster
<i>Baccharis glomeruliflora</i>	Groundsel Tree
<i>B. halimifolia</i>	Saltbush
<i>Balduina angustifolia</i>	Yellow Buttons
<i>B. uniflora</i>	Honeycomb Head
<i>Berlandiera pumila</i>	Green-eyes
<i>Bigelowia nudata</i>	Rayless Goldenrod
<i>B. nuttallii</i>	Narrow Leaf Rayless Goldenrod
<i>Carphephorus odoratissimus</i>	Deer's Tongue
<i>Chrysoma pauciflorescens</i>	Bush Goldenrod
<i>Chrysopsis gossypina</i>	Golden Aster
<i>C. lanuginosa</i>	Bud-drooping Golden Aster
<i>Cirsium nuttallii</i>	Nuttall's Thistle
<i>Conyza canadensis</i>	Horseweed
<i>Elephantopus elatus</i>	Florida Elephant's-Foot
<i>E. tomentosus</i>	Woolly Elephant's-Foot
<i>Erechtites hieracifolia</i>	Fireweed
<i>Erigeron strigosus</i>	Daisy Fleabane
<i>Eupatorium album</i>	White Thoroughwort
<i>E. capillifolium</i>	Dog Fennel
<i>E. compositifolium</i>	Dog Fennel
<i>E. mohrii</i>	Mohr's Eupatorium
<i>Euthamia minor</i>	Flat-topped Goldenrod
<i>Gaillardia aestivalis</i>	Summer Blanketflower
<i>Gnaphalium obtusifolium</i>	Sweet Everlasting
<i>G. purpureum</i>	Purple Cudweed
<i>G. spicatum</i>	Spiked Cudweed
<i>Haplopappus divaricatus</i>	Scratch Daisy
<i>Helianthus radula</i>	Rayless Sunflower
<i>Heterotheca subaxillaris</i>	Camphor Weed
<i>Hieracium gronovii</i>	Hawkweed
<i>Hypochoeris glabra</i>	Smooth Cat's Ear
<i>Krigia virginica</i>	Dwarf Dandelion
<i>Liatris chapmanii</i>	Chapman's Blazing Star
<i>L. elegans</i>	Petaloid-bract Blazing Star
<i>L. gracilis</i>	Common Blazing Star
<i>L. secunda</i>	One-sided Blazing Star
<i>L. spicata</i>	Spicate Blazing Star
<i>L. tenuifolia</i>	Fine-leaf Blazing Star
<i>Pityopsis aspera</i>	Thin-leaved Golden Aster
<i>P. graminifolia</i>	Grass-leaf Golden Aster
<i>P. oligantha</i>	Few-flowered Silk Grass
<i>Pterocaulon pycnostachyum</i>	Blackroot
<i>Silphium compositum</i>	Rosin-weed
<i>Solidago fistulosa</i>	Pinebarren Goldenrod
<i>S. odora</i> var. <i>odora</i>	Sweet Goldenrod
<i>Vernonia angustifolia</i>	Narrow-leaf Ironweed
CONVOLVULACEAE	
<i>Ipomoea macrorrhiza</i>	Large-root Morning-glory
<i>I. pandurata</i>	Wild Potato Vine
<i>Jacquemontia tamnifolia</i>	Small-flowered Morning-glory
<i>Stylisma humistrata</i>	Spreading Stylisma
<i>S. patens</i>	Trailing Stylisma

CRUCIFERAE (BRASSICACEAE)*Warea sessilifolia*

Sessile-leaf Warea

CYRILLACEAE*Cyrilla racemiflora*

Titi

EBENACEAE*Diospyros virginiana*

Persimmon

ERICACEAE*Gaylussacia dumosa*

Dwarf Huckleberry

G. frondosa

Glaucous Huckleberry

G. mosieri

Woolly-berry

Kalmia hirsuta

Hairy Wicky

Lyonia lucida

Fetterbush

Vaccinium arboreum

Sparkleberry

V. corymbosum

Highbush Blueberry

V. darrowii

Darrow's Blueberry

V. elliotii Sy = *V. corymbosum*

Elliott's Blueberry

V. myrsinites

Shiny Blueberry

V. stamineum

Deerberry

EUPHORBIACEAE*Acalypha gracilens*

Slender Three-seeded Mercury

Chamaesyce humistrata

Spurge

Cnidoscolus stimulosus

Tread Softly

Croton argyranthemus

Silver Croton

C. glandulosus

Tropic Croton

Euphorbia curtisii

Curtis' Spurge

E. discoidalis

Round-disc Spurge

E. floridana

Florida Spurge

Sapium sebiferum

Chinese Tallow Tree

Stillingia sylvatica

Queen's Delight

Tragia smallii

Small's Tragia

T. urens

Stinging Tragia

T. urticifolia

Nettle-leaved Tragia

FAGACEAE*Castanea pumila*

Chinquapin

Quercus arkansana

Arkansas Oak

Q. geminata

Sand Live Oak

Q. hemisphaerica

Laurel Oak

Q. incana

Bluejack Oak

Q. laevis

Turkey Oak

Q. margaretta

Sand Post Oak

Q. minima

Dwarf Live Oak

Q. myrtifolia

Myrtle Oak

Q. pumila

Running Oak

Q. virginiana

Live Oak

GUTTIFERAE*Hypericum crux-andreae*

St. Peter's-wort

H. gentianoides

Pineweed

H. hypericoides

St. Andrew's-cross

H. suffruticosum

Little St. Andrew's-cross

H. tetrapetalum

Four-petal St. John's-wort

JUGLANDACEAE*Carya glabra*

Pignut Hickory

C. tomentosa

Mockernut Hickory

KRAMERIAACEAE*Krameria lanceolata***LABIATAE***Calamintha coccinea**C. dentata**Conradina canescens**Pycnanthemum pycnanthemoides**Salvia azurea**Scutellaria glabriuscula**S. incana**Trichostema setaceum***LAURACEAE***Persea borbonia**P. palustris**Sassafras albidum***LEGUMINOSAE (FABACEAE)***Arachis hypogaea**Astragalus villosus**Baptisia calycosa* var. *villosa**B. lanceolata**Cassia deeringiana**C. fasciculata**C. nictitans**C. obtusifolia**Centrosema virginianum**Clitoria mariana**Crotalaria lanceolata**C. purshii**C. rotundifolia**Dalea pinnata* Sy = *Petalostemon pinnatum**Desmodium ciliare**D. glabellum**D. laevigatum**D. lineatum**D. strictum**D. tenuifolium**Galactia erecta**G. floridana**G. macreei**Lespedeza capitata**L. hirta**L. intermedia**L. repens**Lupinus diffusus**L. perennis**L. villosus**Psoralea canescens**P. lupinellus**Rhynchosia cytisoides**R. reniformis**R. tomentosa**Schrankia microphylla**Stylosanthes biflora*

Sandbur

Scarlet Basil

Toothed Savory

Scrub Mint

Pycnanthemum-like Mountain-mint

Blue Sage

Skullcap

Hoary Skullcap

Narrow-leaved Blue Curls

Red Bay

Swamp Bay

Sassafras

Peanut

Hairy Milk-vetch

Hairy Wild Indigo

Pineland Wild Indigo

Red-anthered Partridge-pea

Partridge-pea

Wild Sensitive Plant

Sicklepod

Climbing Butterfly-pea

Butterfly-pea

Lanceleaf Crotalaria

Rattle Box

Rabbit-bells

Summer Farewell

Small-leaved Tick-trefoil

Trailing Tick-trefoil

Smooth Tick-trefoil

Sandhill Round-leaved Beggarweed

Stiff Tick-trefoil

Narrowleaf Tick-trefoil

Erect Milk-pea

Florida Milk-pea

Downy Milk-pea

Round-headed Bush-clover

Hairy Bush-clover

Wand-like Bush-clover

Creeping Bush-clover

Sky-blue Lupine

Sundial Lupine

Lady Lupine

Buckroot

Fine-leaf Psoralea

Pine Barren Pea

Dollar Weed

Tall Rhynchosia

Smooth-leaf Sensitive Brier

Pencil Flower

<i>Tephrosia chrysophylla</i>	Golden Hoary-pea
<i>T. florida</i>	Florida Sand-pea
<i>T. hispidula</i>	Rusty Hoary-pea
<i>T. mohrii</i>	Pineland Hoary-pea
<i>T. spicata</i>	Sand Pea
<i>T. virginiana</i>	Goat's Rue
LINACEAE	
<i>Linum floridanum</i>	Florida Yellow Flax
LOGANIACEAE	
<i>Gelsemium sempervirens</i>	Yellow Jessamine
<i>Polypremum procumbens</i>	Rust Weed
MAGNOLIACEAE	
<i>Magnolia grandiflora</i>	Southern Magnolia
<i>M. virginiana</i>	Sweetbay
MALVACEAE	
<i>Hibiscus aculeatus</i>	Pineland Rose Mallow
MELASTOMACEAE	
<i>Rhexia alifanus</i>	Rose Meadow Beauty
<i>R. mariana</i>	Pale Meadow Beauty
MYRICACEAE	
<i>Myrica cerifera</i>	Wax Myrtle
OLEACEAE	
<i>Osmanthus americanus</i>	Wild Olive
ONAGRACEAE	
<i>Gaura angustifolia</i>	Southern Gaura
<i>G. filipes</i>	Spach's Gaura
<i>Ludwigia virgata</i>	Savannah Seedbox
PHYTOLACCACEAE	
<i>Phytolacca americana</i>	Pokeweed
POLEMONIACEAE	
<i>Phlox floridana</i>	Florida Phlox
<i>P. nivalis</i>	Trailing Phlox
<i>P. pilosa</i>	Downy Phlox
POLYGALACEAE	
<i>Polygala polygama</i>	Milkwort
POLYGONACEAE	
<i>Eriogonum tomentosum</i>	Wild Buckwheat
<i>Polygonella gracilis</i>	Wireweed
<i>Rumex hastatulus</i>	Sourdock
RANUNCULACEAE	
<i>Clematis reticulata</i>	Leather Flower
RHAMNACEAE	
<i>Ceanothus microphyllus</i>	Small-leaf Redroot
ROSACEAE	
<i>Crataegus flava</i>	Summer Haw
<i>C. lacrimata</i>	Weeping Haw
<i>C. uniflora</i>	Dwarf-thorn
<i>Prunus angustifolia</i>	Chickasaw Plum
<i>P. serotina</i>	Black Cherry
<i>Rubus cuneifolius</i>	Sand Blackberry
RUBIACEAE	
<i>Diodia teres</i>	Poor Joe
<i>D. virginiana</i>	Buttonweed
<i>Galium hispidulum</i>	Stiff-haired Bedstraw

<i>G. pilosum</i>	Soft-haired Bedstraw
<i>Hedyotis procumbens</i>	Innocence
<i>Mitchella repens</i>	Partridge Berry
<i>Richardia humistrata</i>	Partridge Berry
<i>Spermacoce prostrata</i>	Slender Buttonweed
SAPOTACEAE	
<i>Bumelia lanuginosa</i>	Black Haw
SCROPHULARIACEAE	
<i>Agalinis divaricata</i>	Little Gerardia
<i>A. setacea</i>	Sandhill Gerardia
<i>Aureolaria flava</i>	Yellow Foxglove
<i>Gratiola hispida</i>	Rough Hedge-hyssop
<i>Linaria canadensis</i>	Blue Toad-Flax
<i>Seymeria cassioides</i>	Black Senna
<i>S. pectinata</i>	Sticky Seymeria
SOLANACEAE	
<i>Physalis arenicola</i>	Ground-cherry
<i>P. virginiana</i>	Southern Ground-cherry
<i>P. viscosa</i>	Rough Ground-cherry
SYMPLOCACEAE	
<i>Symplocos tinctoria</i>	Horse Sugar
UMBELLIFERAE (APIACEAE)	
<i>Eryngium yuccifolium</i>	Rattlesnake Master
VERBENACEAE	
<i>Callicarpa americana</i>	Beautyberry
<i>Stylodon carneus</i>	Flesh-colored Stylodon
VIOLACEAE	
<i>Viola affinis</i>	Florida Violet
<i>V. septemloba</i>	Seven-lobed Violet
VITACEAE	
<i>Vitis rotundifolia</i>	Scuppernong Grape

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APPENDIX B

Terrestrial Arthropod Orders and Families Collected in Restoration and Reference Plots (1994-1996)

Checklist of terrestrial arthropod orders and families encountered in restoration and reference plots using sweep net and modified D-Vac insect vacuum and Malaise trap (1994-96) at Eglin Air Force Base, Florida. Taxa are arranged alphabetically within orders and families.

Nomenclature follows primarily general works by Borror et al. (1989), Kaston (1978), and Stehr (1987, 1991). Where appropriate, more specialized taxonomic references are followed, including Arnett (1968), Goulet and Huber (1993), Marsh et al. (1987), McAlpine et al. (1981, 1987), and Roth (1993).

ARANEAE

Agelenidae
Anyphaenidae
Araneidae
Clubionidae
Ctenizidae
Gnaphosidae
Linyphiidae
Lycosidae
Lyssomanidae*
Micryphantidae
Mimetidae
Nesticidae
Oxyopidae
Philodromidae
Pisauridae
Salticidae
Segestriidae
Tetragnathidae
Theridiidae
Thomisidae

SPIDERS

funnel-web spiders
anyphaenid spiders
orb weavers
sac spiders
trap-door spiders
hunting spiders
sheet-web weavers
wolf spiders
lyssomanid spiders
dwarf spiders
pirate spiders
nesticid spiders
lynx spiders
philodromid crab spiders
nursery-web spiders
jumping spiders
segestriid six-eyed spiders
long-jawed orb weavers
comb-footed spiders
crab spiders

BLATTARIA

Blattellidae

COCKROACHES

German and wood roaches

COLEOPTERA

Alleculidae
Anobiidae
Anthicidae
Anthribidae
Bostrichidae
Bruchidae
Buprestidae
Cantharidae
Carabidae
Cebrionidae*
Cerambycidae
Chrysomelidae
Cicindelidae
Ciidae
Cleridae

BEETLES

comb-clawed beetles
anobiid beetles
antlike flower beetles
fungus weevils
branch and twig borers
seed beetles
metallic wood-boring beetles
soldier beetles
ground beetles
cebrionid beetles
long-horned beetles
leaf beetles
tiger beetles
minute tree-fungus beetles
checkered beetles

*Family considered unlikely to be encountered by a general collector (Borror et al. 1989).

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Coccinellidae	ladybird beetles
Colydiidae	cylindrical bark beetles
Corylophidae	minute fungus beetles
Cryptophagidae	silken fungus beetles
Cucujidae	flat bark beetles
Curculionidae	weevils
Elateridae	click beetles
Erotylidae	pleasing fungus beetles
Euglenidae*	antlike leaf beetles
Histeridae	hister beetles
Lagriidae	long-jointed beetles
Lampyridae	fireflies
Lathridiidae	minute brown scavenger beetles
Leptodiridae	small carrion beetles
Lycidae	net-winged beetles
Melandryidae	false darkling beetles
Meloidae	blister beetles
Melyridae	soft-winged flower beetles
Mordellidae	tumbling flower beetles
Mycetophagidae	hairy fungus beetles
Nitidulidae	sap beetles
Oedemeridae	false blister beetles
Phalacridae	shining flower beetles
Phengodidae*	glowworms
Platypodidae	pin-hole borers
Rhizophagidae	root-eating beetles
Scarabaeidae	scarab beetles
Scydmaenidae*	antlike stone beetles
Scolytidae	bark beetles
Staphylinidae	rove beetles
Tenebrionidae	darkling beetles
Throscidae	throscid beetles

COLLEMBOLA

Entomobryidae
Sminthuridae

SPRINGTAILS

entomobryid springtails
sminthurid springtails

DIPTERA

Acartophthalmidae
Agromyzidae
Anisopodidae
Anthomyiidae
Anthomyzidae
Asilidae
Bibionidae
Bombyliidae
Calliphoridae
Carnidae
Cecidomyiidae
Ceratopogonidae
Chamaemyiidae
Chironomidae
Chloropidae
Chyromyidae
Clusiidae
Conopidae
Culicidae
Curtonotidae

FLIES

acartophthalmid flies
leaf miner flies
wood gnats
anthomyiid flies
anthomyzid flies
robber flies
march flies
bee flies
blow flies
carnid flies
gall midges
no-see-ums
aphid flies
midges
grass flies
chyromyid flies
clusiid flies
thick-headed flies
mosquitoes
curtonotid flies

*Family considered unlikely to be encountered by a general collector (Borror et al. 1989).

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Dolichopodidae	long-legged flies
Drosophilidae	small fruit flies
Empididae	dance flies
Ephydriidae	shore flies
Heleomyzidae	heleomyzid flies
Lauxaniidae	lauxaniid flies
Lonchaeidae	lonchaeid flies
Micropezidae	stilt-legged flies
Milichiidae	milichiid flies
Muscidae	house flies
Mycetophilidae	fungus gnats
Mydidae	mydas flies
Odiniidae	odiniid flies
Otitidae	picture-winged flies
Perisclididae*	perisclidid flies
Phoridae	hump-backed flies
Pipunculidae	big-headed flies
Platypezidae*	flat-footed flies
Platystomatidae	picture-winged flies
Psychodidae	moth flies
Sarcophagidae	flesh flies
Scathophagidae	dung flies
Scatopsidae	minute black scavenger flies
Sciaridae	dark-winged fungus gnats
Sciomyzidae	marsh flies
Sepsidae	black scavenger flies
Simuliidae	black flies
Sphaeroceridae	small dung flies
Stratiomyidae	soldier flies
Syrphidae	syrphid flies
Tabanidae	horse flies, deer flies
Tachinidae	tachinid flies
Tephritidae	fruit flies
Therevidae	stiletto flies
Tipulidae	crane flies
Xylophagidae	xylophagid flies
EPEMEROPTERA	MAYFLIES
Baetidae	baetid mayflies
HEMIPTERA	BUGS
Aradidae	flat bugs
Berytidae	stilt bugs
Coreidae	leaf-footed bugs
Lygaeidae	seed bugs
Miridae	plant bugs
Pentatomidae	stink bugs
Pyrrhocoridae	red bugs
Reduviidae	assassin bugs
Rhopalidae	scentless plant bugs
Tingidae	lace bugs
HOMOPTERA	HOPPERS, APHIDS, PSYLLIDS, WHITEFLIES, SCALE INSECTS
Aleyrodidae	whiteflies
Aphididae	aphids
Cercopidae	spittlebugs
Cicadellidae	leafhoppers

*Family considered unlikely to be encountered by a general collector (Borror et al. 1989).

APPENDIX B

Coccoidea	scale insects
Eriosomatidae	wooly aphids
Fulgoroidea:	fulgoroid planthoppers:
Acanaloniidae	acanaloniid planthoppers
Achilidae	achilid planthoppers
Cixiidae	cixiid planthoppers
Delphacidae	delphacid planthoppers
Derbidae	derbid planthoppers
Dictyopharidae	dictyopharid planthoppers
Flatidae	flatid planthoppers
Fulgoridae	fulgorid planthoppers
Issidae	issid planthoppers
Membracidae	treehoppers
Psyllidae	psyllids
Phylloxeridae	phylloxerans

HYMENOPTERA

Ampulicidae
 Andrenidae
 Anthophoridae
 Bethyidae
 Braconidae
 Ceraphronidae
 Chalcidoidea:
 Aphelinidae
 Chalcididae
 Elasmidae
 Encyrtidae
 Eucharitidae
 Eulophidae
 Eupelmidae
 Eurytomidae
 Mymaridae
 Ormyridae
 Perilampidae
 Pteromalidae
 Signiphoridae*
 Torymidae
 Trichogrammatidae
 Chrysididae
 Colletidae
 Crabronidae
 Cynipidae
 Diapriidae
 Dryinidae
 Embolemidae*
 Eucoilidae
 Evaniidae
 Figitidae
 Formicidae
 Halictidae
 Ichneumonidae
 Megachilidae
 Megaspilidae
 Mutillidae
 Nyssonidae
 Pemphredonidae
 Pergidae*

BEEES, WASPES, ANTS, SAWFLIES

ampulicid wasps
 andrenid bees
 cuckoo bees
 bethyid wasps
 braconid wasps
 ceraphronid wasps
 chalcidoid wasps:
 aphelinid wasps
 chalcidid wasps
 elasmid wasps
 encyrtid wasps
 eucharitid wasps
 eulophid wasps
 eupelmid wasps
 seed chalcids
 fairyflies
 ormyrid wasps
 perilampid wasps
 pteromalid wasps
 signiphorid wasps
 torymid wasps
 trichogrammatid wasps
 cuckoo wasps
 plasterer bees
 crabronid wasps
 gall wasps
 diapriid wasps
 dryinid wasps
 embolemid wasps
 eucoilid wasps
 ensign wasps
 figitid wasps
 ants
 sweat bees
 ichneumonid wasps
 leaf-cutter bees
 megaspilid wasps
 velvet ants
 nyssonid wasps
 pemphredonid wasps
 pergid wasps

*Family considered unlikely to be encountered by a general collector (Borror et al. 1989).

APPENDIX B

Philanthidae	philanthid wasps
Platygastridae	platygastriid wasps
Pompilidae	spider wasps
Proctotrupidae	proctotrupid wasps
Rhopalosomatidae*	rhopalosomatid wasps
Sapygidae*	sapygid wasps
Scelionidae	scelionid wasps
Scoliidae	scoliid wasps
Sphecidae	sphecid wasps
Tenthredinidae	common sawflies
Tiphiidae	tiphiid wasps
Vespidae	paper wasps, hornets
ISOPTERA	TERMITES
Kalotermitidae	kalotermitid termites
Rhinotermitidae	rhinotermitid termites
LEPIDOPTERA	BUTTERFLIES, MOTHS
Arctiidae	tiger moths
Coleophoridae	casebearers
Geometridae	inchworms
Heliconiidae	heliconians
Hesperiidae	skippers
Lycaenidae	coppers, hairstreaks, blues
Noctuidae	noctuid moths
Notodontidae	prominents
Nymphalidae	brush-footed butterflies
Pieridae	whites, sulphurs, orange-tips
Psychidae	bagworms
Sesiidae	clearwing moths
Sphingidae	sphinx moths
MANTODEA	MANTIDS
Mantidae	praying mantids
MECOPTERA	SCORPIONFLIES
Panorpidae	common scorpionflies
NEUROPTERA	LACEWINGS, ANTLIONS, OWLFLIES
Ascalaphidae	owlflies
Berothidae*	beaded lacewings
Chrysopidae	green lacewings
Coniptyrigidae*	dusty-wings
Hemerobiidae	brown lacewings
Myrmeleonidae	antlions
Sisyridae	spongillaflyies
ORTHOPTERA	GRASSHOPPERS, CRICKETS, KATYDIDS
Acrididae	grasshoppers
Gryllacrididae	wingless long-horned grasshoppers
Gryllidae	crickets
Tetrigidae	pygmy grasshoppers
Tettigoniidae	katydids
PHASMIDA	WALKINGSTICKS
Pseudophasmatidae	striped walkingsticks

*Family considered unlikely to be encountered by a general collector (Borror et al. 1989).

APPENDIX B

PSOCOPTERA

Hemipsocidae
Lepidopsocidae
Psocidae

PSOCIDS

hemipsocids
lepidopsocids
psocids

THYSANOPTERA

Phlaeothripidae

THRIPS

phlaeothripid thrips

*Family considered unlikely to be encountered by a general collector (Borror et al. 1989).

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APPENDIX C

Identified Herb-layer Arthropod Species/Morphospecies Collected in Restoration and Reference Plots (1994-1996)

Checklist of identified herb-layer arthropod species/morphospecies encountered in restoration and reference plots using sweep net and modified D-Vac insect vacuum (1994-96) at Eglin Air Force Base, Florida. Taxa are arranged alphabetically within orders and families. Since the vast majority of arthropod species do not have a common name approved by the Entomological Society of America, we have not attempted to assign common names below.

Nomenclature follows primarily general works by Borror et al. (1989), Kaston (1978), and Stehr (1987, 1991). Where appropriate, more specialized taxonomic references are followed, including Arnett (1968), Goulet and Huber (1993), Marsh et al. (1987), McAlpine et al. (1981, 1987), and Roth (1993).

COLEOPTERA (BEETLES)

ANTHRIBIDAE

Trigonorhinus rotundatus (LeConte)

CHRYSOMELIDAE

Altica spp.

Anisostena nigrita (Olivier)

Chaetocnema sp.

Chlamisus sp.

Colaspis costipennis Crotch

Coscinoptera dominicana dominicana (Fabricius)

Cryptocephalus albicans Haldeman

Cryptocephalus binominis binominis Newm.

Disonycha caroliniana (Fabricius)

Epitrix solani (Blatchley)

Exema sp.

Glyptina bicolor Horn

Hemisphaerota cyanea (Say)

Lexiphanes affinis (Haldeman)

Longitarsus sp.

Longitarsus testaceus Melsheimer

Metachroma pellucidum Crotch

Metachroma quercatum (Fabricius)

Oulema cornuta (Fabricius)

Pachybrachis varians(?) Bowditch

Pachybrachis spp.

Saxinus omogera Lacordaire

Triachus atomus (Suffrain)

Triachus cerinus LeConte

COCCINELLIDAE

Brachiacantha decempustulata (Melsh.)

Diomus debilis (LeConte)

Diomus terminatus (Say)

Exochomus marginipennis (LeConte)

Hyperaspis proba (Say)

Hyperaspis sp.

Psyllobora parvinotata Casey
Scymnus cervicalis Mulsant
Scymnus (Scymnus) sp.
Zilus horni Gordon

CURCULIONIDAE

Apion sp.

MELYRIDAE

Attalus circumscriptus Say
Attalus sp.
Collops sp.
Temnosophus sp.

COLLEMBOLA (SPRINGTAILS)**ENTOMOBRYIDAE**

Entomobrya assuta Folsom
Entomobryoides purpurascens (Packard)
Orchesella sp.
Salina banksi MacGillivray
 Undetermined #4

SMINTHURIDAE

Bourletiella sp.
Sminthurus (Sminthurus) carolinensis Snider
Sminthurus (Sminthurus) floridanus (MacGillivray)
Sminthurinus (Katiannina) macgillivrayi (Banks)

DIPTERA (FLIES)**ASILIDAE**

Efferia sp.
Holopogon sp.
Leptogaster sp.
Stichopogon sp.

CHLOROPIDAE

Ceratobarys eulophus (Loew)
Conioscinella grisescens (Sabrosky)
Ectecephala sp.
Hippelates sp.
 Undetermined #3
 Undetermined #6
 Undetermined #7
 Undetermined #8

EMPIDIDAE

Drapetis sp.
Euhybus sp.
Platypalpus sp.
Trichina sp.
 Undetermined #1

LAUXANIIDAE

Melanomyza sp.
Poecilolycia sp.
Poecilominettia valida (Walker)
Steganolauxania sp.

MILICHIIDAE*Milichiella lacteipennis* (Loew)*Phleomyia* sp.*Paramyia nitens* (Loew)

Undetermined #4

PLATYSTOMATIDAE*Rivellia metallica* (Wulp)**HOMOPTERA (HOPPERS, ETC.)****ACANALONIIDAE***Acanalonia latifrons* Walker**ACHILIDAE***Catonia bicinctura* van Duzee

Undetermined #2

Undetermined #3

CICADELLIDAE*Alebra* sp.*Balclutha guajanae* (DeLong)*Draeculocephala septemguttata* (Walker)*Empoasca* spp.*Erythroneura* spp.*Eutettix tristis* Ball*Paralobocratus flavidus* Signoret*Paraphlepsius mimus* (?) (Baker)*Penthimia* sp.*Polana quadrinotata* (Spangberg)*Rugosana querci* DeLong*Scaphoideus* sp.*Scaphytopius rubillus* ? (Sand. & DeLong)

Undetermined #25

Undetermined #26

Undetermined #27

Undetermined #28

Undetermined #29

Undetermined #30

Undetermined #31

Undetermined #32

Undetermined #33

Undetermined #34

Undetermined #35

Undetermined #36

Undetermined #37

Undetermined #38

Undetermined #39

Undetermined #40

Undetermined #41

Undetermined #42

Undetermined #43

Undetermined #44

CIXIIDAE*Oecleus* sp.

Oliarus vicarius

DELPHACIDAE

Liburnella ornata Stål

Undetermined #2

Undetermined #3

Undetermined #4

Undetermined #5

Undetermined #6

Undetermined #7

Undetermined #8

Undetermined #9

DERBIDAE

Cedusa sp.

Gmolicna proxima Fennah

DICTYOPHARIDAE

Rhynchomitra lingula(van Duzee)

Undetermined #2

Undetermined #3

FLATIDAE

Metcalfa pruinosa (Say)

FULGORIDAE

Cyrpoptus reinecke van Duzee

ISSIDAE

Bruchomorpha minima Metcalf

Hysteropterus punctiferum Walker

HYMENOPTERA (BEES, WASPS, ANTS, SAWFLIES)

EUCHARITIDAE

Orasema nr. *bakeri* Graham

BRACONIDAE

Apanteles sp.

Aspilota sp.

Chelonus sp.

Heterospilus sp.

Mirax sp.

Muesebeckia sp.

Opius sp.

Orthostigma sp.

Phanerotoma sp.

FORMICIDAE

Aphaenogaster treatae Forel

Brachymyrmex depilis Emery

Brachymyrmex "*musculus*"

Camponotus floridanus (Buckley)

Camponotus nearcticus Emery

Camponotus socius Roger

Crematogaster ashmeadi Mayr

Cyphomyrmex sp.

Dolichoderus pustulatus Mayr

Dorymyrmex bureni (Trager)

Dorymyrmex grandulus (Forel)

Forelius pruinus (Roger)
Formica pallidefulva Latreille
Formica schaufussi Mayr
Leptothorax pergandei Emery
Leptothorax texanus Wheeler
Monomorium viride Brown
Paratrechina wojciki Trager
Pheidole adrianoi Naves
Pheidole dentata Mayr
Pheidole floridana Emery
Pheidole metallescens Emery
Pheidole morrisoni Forel
Prenolepis imparis (Say)
Pseudomyrmex ejectus (Smith)
Pseudomyrmex pallidus (Smith)
Smithistruma margaritae (Forel)
Solenopsis abdita Thompson
Solenopsis picta Emery
Trachymyrmex septentrionalis (McCook)

ARANEAE (SPIDERS)

ARANEIDAE

Acacesia hamata (Hentz)
Acanthepeira stellata (Marx)
Araneus sp.
Argiope sp.
Eustala sp.
Gea heptagon (Hentz)
Larinia sp.
Mangora gibberosa (Hentz)
Mecynogea lemniscata (Walckenaer)
Metepeira sp.
Micrathena gracilis (Walckenaer)
Ocrepeira sp.
Nephila sp.

LYSSOMANIDAE

Lyssomanes viridis (Walckenaer)

MIMETIDAE

Mimetus sp.

OXYOPIDAE

Hamataliwa sp.
Oxyopes sp.
Peucetia viridans (Hentz)

PHILODROMIDAE

Ebo sp.
Philodromus sp.
Tibellus oblongus (Walckenaer)

SALTICIDAE

Eris sp.
Habrocestum sp.
Habronattus sp.
Hentzia sp.

Maevia sp.
Marpissa sp.
Metaphidippus sp.
Phidippus sp.
Sarinda sp.
Sassacus sp.
Synageles sp.
Synemosyna lunata (Walckenaer)
Zygoballus sp.

THOMISIDAE

Misumenoides formosipes (Walckenaer)
Misumenops sp.
Ozyptila sp.
Tmarus sp.
Xysticus sp.

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APPENDIX D

Bird Species Encountered During Sampling in Restoration and Reference Plots

BREEDING SEASON

<u>COMMON NAME</u>	<u>SCIENTIFIC NAME</u>
American Crow	<i>Corvus brachyrhynchos</i>
American Kestrel	<i>Falco sparverius</i>
Bachman's Sparrow	<i>Aimophila aestivalis</i>
Barn Swallow	<i>Hirundo rustica</i>
Blue Grosbeak	<i>Guiraca caerulea</i>
Blue Jay	<i>Cyanocitta cristata</i>
Blue-gray Gnatcatcher	<i>Poliophtila caerulea</i>
Broad-winged Hawk	<i>Buteo platypterus</i>
Brown Thrasher	<i>Toxostoma rufum</i>
Brown-headed Nuthatch	<i>Sitta pusilla</i>
Carolina Chickadee	<i>Parus carolinensis</i>
Carolina Wren	<i>Thryothorus ludovicianus</i>
Cattle Egret	<i>Bubulcus ibis</i>
Cedar Waxwing	<i>Bombycilla cedrorum</i>
Chimney Swift	<i>Chaetura pelagica</i>
Chuck-will's-widow	<i>Caprimulgus carolinensis</i>
Common Grackle	<i>Quiscalus quiscula</i>
Common Nighthawk	<i>Chordeiles minor</i>
Downy Woodpecker	<i>Picoides pubescens</i>
Eastern Bluebird	<i>Sialia sialis</i>
Eastern Kingbird	<i>Tyrannus tyrannus</i>
Eastern Meadowlark	<i>Sturnella magna</i>
Eastern Towhee	<i>Pipilo erythrophthalmus</i>
Eastern Wood-Pewee	<i>Contopus virens</i>
Eastern Screech-Owl	<i>Otus asio</i>
Fish Crow	<i>Corvus ossifragus</i>
Great Crested Flycatcher	<i>Myiarchus crinitus</i>
Great Horned Owl	<i>Bubo virginianus</i>
Hairy Woodpecker	<i>Picoides villosus</i>
Indigo Bunting *	<i>Passerina cyanea</i>
Kentucky Warbler *	<i>Oporornis formosus</i>
Least Tern	<i>Sterna antillarum</i>
Loggerhead Shrike	<i>Lanius ludovicianus</i>
Mississippi Kite *	<i>Ictinia mississippiensis</i>
Mourning Dove	<i>Zenaida macroura</i>
Northern "Yellow-shafted" Flicker	<i>Colaptes auratus</i>
Northern Bobwhite	<i>Colinus virginianus</i>
Northern Cardinal	<i>Cardinalis cardinalis</i>
Northern Mockingbird	<i>Mimus polyglottos</i>
Orchard Oriole *	<i>Icterus spurius</i>
Pileated Woodpecker	<i>Dryocopus pileatus</i>
Pine Warbler	<i>Dendroica pinus</i>
Purple Martin	<i>Progne subis</i>
Red-bellied Woodpecker	<i>Melanerpes carolinus</i>
Red-cockaded Woodpecker	<i>Picoides borealis</i>
Red-eyed Vireo	<i>Vireo olivaceus</i>
Red-headed Woodpecker	<i>Melanerpes erythrocephalus</i>

Red-shouldered Hawk	<i>Buteo lineatus</i>
Red-tailed Hawk	<i>Buteo jamaicensis</i>
Red-winged Blackbird	<i>Agelaius phoeniceus</i>
Summer Tanager	<i>Piranga rubra</i>
Tufted Titmouse	<i>Baeolophus bicolor</i>
Yellow-billed Cuckoo	<i>Coccyzus americanus</i>
Yellow-breasted Chat *	<i>Icteria virens</i>
Yellow-throated Vireo	<i>Vireo flavifrons</i>
White-eyed Vireo	<i>Vireo griseus</i>

* 1997 addition

WINTER SEASON

COMMON NAME

American Crow *
 American Goldfinch *
 American Kestrel *
 American Robin *
 Bachman's Sparrow
 Barn Swallow
 Blue-headed Vireo *
 Blue Jay *
 Blue-gray Gnatcatcher *
 Brown Thrasher *
 Brown-headed Cowbird
 Brown-headed Nuthatch *
 Carolina Chickadee *
 Carolina Wren *
 Cedar Waxwing
 Chipping Sparrow *
 Common Grackle
 Common Snipe
 Dark-eyed "Slate-colored" Junco *
 Downy Woodpecker *
 Eastern Bluebird *
 Eastern Meadowlark
 Eastern Phoebe *
 Eastern Screech-Owl
 Eastern Towhee *
 Fish Crow
 Golden-crowned Kinglet
 Gray Catbird
 Great Horned Owl
 Hairy Woodpecker *
 Hermit Thrush *
 House Wren *
 Loggerhead Shrike
 Mourning Dove
 Northern "Yellow-shafted" Flicker *
 Northern Bobwhite
 Northern Cardinal *
 Palm Warbler *
 Pileated Woodpecker *

SCIENTIFIC NAME

Corvus brachyrhynchos
Carduelis tristis
Falco sparverius
Turdus migratorius
Aimophila aestivalis
Hirundo rustica
Vireo solitarius
Cyanocitta cristata
Poliophtila caerulea
Toxostoma rufum
Molothrus ater
Sitta pusilla
Parus carolinensis
Thryothorus ludovicianus
Bombcilla cedorum
Spizella passerina
Quiscalus quiscula
Gallinago gallinago
Junco hyemalis
Picoides pubescens
Sialia sialis
Sturnella magna
Sayornis phoebe
Otus asio
Pipilo erythrophthalmus
Corvus ossifragus
Regulus satrapa
Dumetella carolinensis
Bubo virginianus
Picoides villosus
Catharus guttatus
Troglodytes aedon
Lanius ludovicianus
Zenaida macroura
Colaptes auratus
Colinus virginianus
Cardinalis cardinalis
Dendroica palmarum
Dryocopus pileatus

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Pine Warbler *	<i>Dendroica pinus</i>
Purple Finch * *	<i>Carpodacus purpureus</i>
Purple Martin	<i>Progne subis</i>
Red-bellied Woodpecker *	<i>Melanerpes carolinus</i>
Red-breasted Nuthatch *	<i>Sitta canadensis</i>
Red-cockaded Woodpecker *	<i>Picoides borealis</i>
Red-shouldered Hawk	<i>Buteo lineatus</i>
Red-tailed Hawk	<i>Buteo jamaicensis</i>
Red-winged Blackbird *	<i>Agelaius phoeniceus</i>
Ruby-crowned Kinglet *	<i>Regulus calendula</i>
Tufted Titmouse *	<i>Baeolophus bicolor</i>
Turkey Vulture	<i>Cathartes aura</i>
Whip-poor-will	<i>Caprimulgus vociferus</i>
White-throated Sparrow *	<i>Zonotrichia albicollis</i>
Wild Turkey	<i>Meleagris gallopavo</i>
Yellow-bellied Sapsucker *	<i>Sphyrapicus varius</i>
Yellow-rumped "Myrtle" Warbler *	<i>Dendroica coronata</i>

* 1996/97 addition

* collected ≥ 1 foraging observation

APPENDIX E

Descriptions of Foraging Maneuvers and Substrates Used in Winter Bird Foraging Study

Foraging Maneuvers

Flake: to brush aside loose substrate, such as bark, with sideways sweeping motions of the bill

Glean: to pick food items from a nearby substrate

Peck: to drive the bill against the substrate to remove some of the exterior of the substrate

Probe: to insert the bill into cracks or holes in firm substrate or directly into softer substrates to capture hidden food

Search: includes any movements used to find food exposed or hidden on substrates, i.e. hopping among branches, climbing tree boles, hanging from twigs or branches, hovering at leaves

Other:

Hawk: an aerial maneuver in which a bird flies from a perch to attack a food item that is either on a hard substrate or in the air

Unknown: observed behavior is not readily identifiable

With prey: bird is observed with a food item, either animal or plant food

With seed: bird is observed with *Pinus palustris* seed

With arthropod: bird is observed with insect, spider, or other arthropod prey

Foraging Substrates

Bole: tree bole; the main trunk of a tree

Branch: tree branch; the main woody divisions of a tree that make up the crown

Cone: pine cone; the seed-bearing structure of a pine or other coniferous tree

Leaf: the flattened structure attached to the stem of a deciduous or hardwood tree

Needle: the linear leaf of a coniferous or softwood tree

Needle-bundle: a fascicle or clump of needles

Stub: a short, broken-off dead branch or twig; often barkless

Twig: tree twig; a small, slender woody stem